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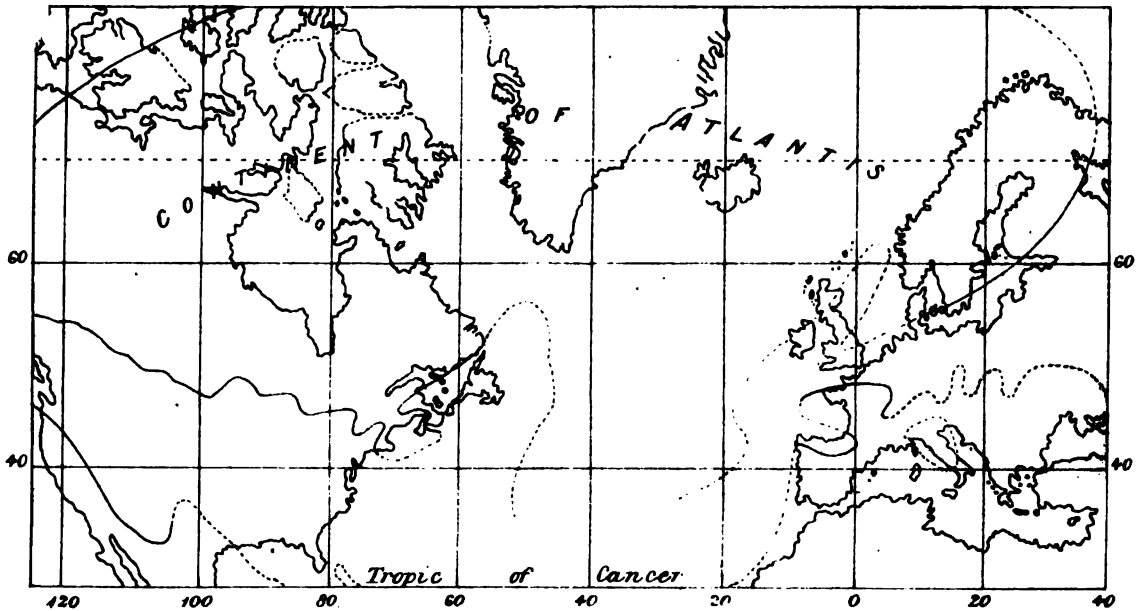
# THE STUDENT'S HANDBOOK OF HISTORICAL GEOLOGY.

# SKETCH MAP,

SHOWING THE RELATIVE POSITIONS OF

LAND AND SEA AT THE CLOSE OF THE CARBONIFEROUS PERIOD.

*Land Areas are tinted* BROWN; *Submerged Areas,* BLUE.



# THE STUDENT'S HANDBOOK

OF

# HISTORICAL GEOLOGY.

BY

A. J. JUKES-BROWNE, B.A., F.G.S.,

OF THE GEOLOGICAL SURVEY OF ENGLAND AND WALES.

*With numerous Diagrams and Illustrations.*

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# PREFACE.

A FORMER volume having been devoted to Physical and Structural Geology, the student's curriculum is now completed by a short treatise on Palæontological and Historical Geology, in accordance with the scheme set out in the Introduction to the first volume. It may be thought that the section devoted to Palæontology should have been fuller, and should have included some description of those forms of life which are most frequently met with in a fossil state. This was indeed my intention, but a trial convinced me that a brief summary would be of very little use, and that for the proper treatment of the subject a separate volume would be required.

In the Historical section I have endeavoured to give as full an account of the rocks of Great Britain and Ireland as space would permit, supplementing this with only so much of continental geology as is necessary to fill up the gaps in the British records, and to complete the outline of Geological History. The literature of British Geology is beginning to attain very large proportions, but in spite of the large amount of information which has been obtained, there are many areas (especially of Palæozoic rocks) about which very little is yet known; and in other cases, though the local succession is known, yet authorities differ as to the exact age and correlation of the several rock-groups. Systematic nomenclature is another difficulty, for as our

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knowledge increases alterations in the classification and nomenclature of one or other of the rock-groups often become desirable, but any alterations proposed are always productive of much discussion and difference of opinion. Under these circumstances, the compiler of a students' handbook frequently finds it difficult to decide whether he should follow some one authority, or endeavour to extract truth and justice from conflicting statements, and often indeed he is forced to form his own opinion on the facts brought forward by different observers. Where, therefore, I have presumed to take an independent course, this necessity must be my excuse.

Prominence has been given to such stratigraphical facts as throw light on the physical and geographical conditions under which each group or system of rocks has been accumulated. It is only of late years that our knowledge has become sufficiently complete to furnish grounds for the establishment of Palæo-Geography as a branch of Geology, and much more information is yet required before we can confidently restore the physical geography of Britain in any but the very latest phases of its history. The farther we go back in time the fewer are the data upon which we can build, and I am therefore quite aware that in attempting to give a brief but definite sketch of the geography of each successive period, and in indicating the changes which seem to have taken place in the relative positions of land and sea, I have ventured into fields of doubt and difficulty. In making the attempt, however, I have availed myself of the material already collected by Professor Hull in his "Contributions to the Physical History of Great Britain," and I have endeavoured in each case to confine myself to such inferences as might reasonably be deduced from a study of the facts without entering too far into the realms of scientific speculation.

To Professor Lapworth, who kindly read the chapters on Archæan and Palæozoic rocks, I am indebted for many suggestions; and to Professor Bonney, Dr. Hicks, Mr. H. B. Woodward, Mr. Hugh Miller, Mr. A. Strahan, and Mr. Mellard Reade, my best thanks are due for similar assistance in other portions of the book.

The figures of fossil plants and animals have been introduced to familiarize the student with the forms of such fossils, and I feel sure that many will welcome the re-appearance of some of the excellent groups which were drawn by Mr. Baily for Jukes' "Manual of Geology." Of the rest many are borrowed from Dr. Mantell's works; some few were drawn by myself and reproduced by Messrs. Dawson's photographic process, as were also Figs. 59 and 99 from drawings by Mr. G. Sharman.

Sections illustrative of the geological structure of the country are so useful a means of conveying information and of fixing it in the mind of the student, that I regard them a necessary adjunct to a book which is intended for teaching purposes. No fewer than fifty such sections have therefore been inserted in this volume; some of them are borrowed from the pages of the Geological Society and the Geologists' Association, and for the use of these cuts my acknowledgments are due to the authors of the several articles and to the Councils of the above-mentioned societies.

The frontispiece is a reprint of one of the plates illustrating Professor Hull's paper on the Geological Age of the North Atlantic Ocean in the Transactions of the Royal Dublin Society, and for its use I am indebted to the kindness of Professor Hull and the Scientific Committee of that Society.

In preparing these two volumes I have kept my object steadily in view, viz., to furnish teachers with a useful

class-book of Geology; accuracy, a proportional treatment of subjects, and a clear method of arrangement, are essential to the usefulness of such a book, and I hope this little treatise will be found to possess these in such measure as to commend it to the favour of those persons for whose use it is meant.

A. J. JUKES-BROWNE.

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# INTRODUCTION.

**SCOPE of the Subject.**—In some manuals of Geology this branch of the subject is called Stratigraphical Geology, because it chiefly consists in the description of the great stratified series of rocks which make up the mass of the earth's crust. But Stratigraphical Geology is really only the foundation upon which a more complete history should be built up: Historical Geology should comprise not only a description of the various rocks which were formed during each period of the world's history, but also some account of the forms of life which are entombed in these rocks, with a sketch of the physical geography of the earth during each period, and a notice of the changes in the relative position of land and sea which took place from time to time: all this should be made as complete as the imperfection of the geological documents will allow.

In brief, Historical Geology should gather up the knowledge acquired in all the other departments of the science, and should apply it to the elucidation of the history of the earth, or of a portion of the earth, from the earliest time of which any records exist down to the time of human history.

At present there are only a few limited areas of the earth's surface about which we have anything like a full stratigraphical knowledge, and much remains to be learnt even in the areas about which we know most. Historical Geology, therefore, is yet in its infancy; but enough is now known of the stratigraphical geology of Europe to make it possible to give an outline of its geological history, and American geologists are rapidly making it possible to do the same for North America. In this volume, however, we



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shall not travel beyond the limits of the British Islands, except where our own records are deficient, or where some knowledge of continental geology is necessary to the proper understanding of the changes that took place in Britain.

**The Succession of Stratified Rocks.**—The general principles on which Historical Geology is founded are easily understood, and the manner in which the order and succession of rock-groups is established will now be briefly explained. The mere succession of strata in any district or country, however, is one thing, and the grouping of such strata into larger systems, representing definite geological periods, is another thing, and one which requires consideration from several points of view. A subsequent chapter, therefore, will be devoted to a discussion of the principles upon which divisional lines may be drawn in any established succession of rock-groups.

The two principal tests by which the relative age of different strata is determined are—(1), Superposition; (2), Fossil contents.

In the first volume of this work (Part II. Chapter V.), the conclusions to be drawn from the superposition of strata were explained, and it was stated that the law of vertical succession formed the basis upon which the whole fabric of historical geology was founded :—" In any succession of beds each one represents the conditions which prevailed over a certain area for a certain length of time, the lowest is the oldest, the uppermost is the newest, and the relative age of the others is indicated by their relative position." If the strata are inclined, the right order is ascertained by the methods indicated in Chapter VII. of the same Part, namely, by making a geological survey of the district, and constructing a section at right angles to the general general strike of the beds.

Again, by tracing any one set of strata horizontally along their strike from one part of a district to another, where perhaps there are other rocks of a different kind, we obtain a datum of reference by which to determine whether the rocks in the second area are newer or older than those in the first.

So long as there is physical and geological continuity between the different portions of a district—*i,e.*, so long as

some one member of a comformable series of strata can be followed continuously, such a survey generally affords sufficient data for ascertaining the relative position of the rocks which occur in the district, and for constructing a table of their vertical succession. But when either geographical or geological continuity is interrupted—that, is, when a district or country is separated from others where similar rocks occur either by the sea or by tracts of totally different rocks—then we must begin all over again, and construct an independent table of strata for the new district. For example, Wales is a district to all parts of which one system of classification and nomenclature can be applied. Similar groups of rocks occur in Ireland on the one hand, and in Cumberland on the other; but Wales is physically separated from Ireland by the Irish Sea, and geologically separated from Cumberland by the Triassic plains of Cheshire and Lancashire; hence the same system of nomenclature could not be used in the other districts, the vertical succession had to be determined independently, and local names given to the different sub-divisions in each district, before they could be in any way compared with one another.

But, it may be asked, when two such districts have been independently investigated, how are we to correlate the two tables of strata, and ascertain which rocks or rock-groups were approximately contemporaneous? It it here that a knowledge of fossils or Palæontology comes to our aid, and enables us to identify rocks by their fossil contents, so that strata in different districts and of different lithological characters may be included in the same natural group or system, because they contain the same or closely similar species of fossils. This was the principle discovered and applied at the beginning of this century by Dr. William Smith, who is often called the Father of British Geology, and who was certainly the founder of that branch of the science which is the subject of the present volume.

There are, however, certain limitations in the application of palæontological evidence which cannot be properly explained until some knowledge of the laws which regulate the distribution of species in present and past time has been acquired. To this subject two short chapters will be devoted; and the principles upon which the geological series

is divided into separate systems will be more fully explained in a third chapter: but meanwhile the ultimate results are given below, in the form of a list of the larger divisions which are usually accepted as systems.

In the early days of systematic geology the systems then known were arranged under three comprehensive sections, which were called Primary, Secondary, and Tertiary; and it was supposed that the rocks belonging to these eras of time differed essentially in their original nature and mode of formation. Subsequent investigation proved this idea to be an error, and Prof. Phillips consequently proposed another set of names for the eras based on palæontological facts, namely, *Palæozoic*, *Mesozoic* and *Cænozoic*, signifying respectively times of ancient, middle and recent life. The two former of these have been very generally adopted, but Tertiary is still preferred to Cænozoic, and there is no reason now why its correlatives, Primary and Secondary, should not be employed as time-words, instead of the more cumbrous Palæozoic and Mesozoic.

Prof. Forbes thought that the faunas of the Secondary and Tertiary had so great an affinity that the whole succession was more naturally divisible into two eras, which he termed Palæozoic and Neozoic: possibly this plan may be eventually adopted, but at present the Primary, Secondary and Tertiary (or Palæozoic, Mesozoic and Cænozoic) are accepted as convenient divisions of geological time. It is true that much difference of opinion exists as to the exact limit of Palæozoic life and time, but this difficulty may be avoided by regarding the Dyas as a transition group between the two eras.

Since these terms were proposed, however, a series of stratified rocks have been discovered below those which were called Primary or Palæozoic, and for these several names have been proposed; of these *Archæan* is the best, for the others, *Azoic* and *Eozoic*, are founded on the respective assumptions (1) that they contain no organic remains, (2) that they contain the relics of the first dawn of life in the world. If life is ever discovered in these rocks, it will probably be of Palæozoic type, but the Archæan is at present excluded from the Palæozoic era.

In the following list the newest system is written first,

and the oldest last to indicate that the chronology is determined by the superposition of the systems.

| | Eras. | | Systems. |
|---|---|---|---|
| Neozoic | Tertiary or Cænozoic | | Pleistocene.[1] |
| | | | Pliocene. |
| | | | Miocene. |
| | | | Oligocene. |
| | | | Eocene. |
| | Secondary or Mesozoic. | | Cretaceous. |
| | | | Jurassic. |
| | | | Triassic. |
| | | | Dyassic. |
| | Primary or Palæozoic | | Carboniferous. |
| | | | Devonian. |
| | | | Silurian. |
| | | | Ordovician. |
| | | | Cambrian. |
| | Azoic? | = | Archæan. |

From what has been said above, it is obvious that some previous knowledge of Physical Geology and of Palæontology is a necessary preparation to the study of Historical Geology. Some account of the former has been given in the first volume of this work; but Palæontology is a separate science, and would require a treatise to itself; so that in the present volume space can only be found for the mention of certain facts and considerations regarding the distribution of life and the preservation of fossils which have a special bearing on the history and classification of rocks.

[1] Reasons will be given in Chapter III. for reducing the number of the Tertiary systems to two, but the divisions here given are those which are usually recognised as systems.

# PART IV.

## THE LAWS AND APPLICATIONS OF PALÆONTOLOGY.

*A brief Account of the Principles which should guide us in constructing a Chronological Classification of the Rocks which compose the earth's crust.*

# CHAPTER I.

## GEOGRAPHICAL DISTRIBUTION OF LIFE.

SINCE organic remains afford such valuable aid in the task of classifying and correlating the different series of rocks which occur in different districts and countries, it is necessary that the geological student should become acquainted with the nature and proper use of palæontological evidence. In the present volume we are obliged to assume that the reader has some knowledge of Biology, both recent and fossil, to the extent at least of knowing the appearance and general structure of the organisms included in the different classes and orders into which the animal and vegetable kingdoms are usually divided. We propose, however, to give a brief sketch of the laws and conditions which regulate the distribution of modern animals and plants, inasmuch as it is only through a knowledge of these that we can hope to understand the distribution of life in past times, and to avoid error in the use of palæontological evidence.

**Distribution of Life in Climatal Belts and Stations.**—Naturalists who made careful collections of the animals and plants which lived in any area either of land or sea, were not long in perceiving that different groups of species inhabited different tracts or spaces, and that the limits of their distribution depended on various conditions, such as soil, food, temperature and depth of water.

Thus on land the range of plants is greatly determined by temperature and height above the sea-level, and secondarily by the nature of the soil. The range of plant-eating

animals depends partly on temperature and partly on the presence of the plants they feed upon; that of carnivorous animals is similarly, though less strictly limited.

In the sea, among those creatures which live on the bottom, we find similar restrictions—the conditions of depth, including difference of temperature, increase of pressure and loss of light, produce a corresponding vertical or zonal arrangement, some species being only found near the shore, others in deeper water, and others again in the depths of the ocean.

The climatal variations depending on height above sea-level and depth below it, are so important that it is possible to divide all space both above and below the sea-level into tracts or belts, each being characterised by certain forms of life, both animal and vegetable. Thus Meyen recognized eight vertical botanical belts under the equator, characterized as follows:—

| | Height in feet. |
|---|---|
| Region of perpetual snow, without plants. | 16,200 |
| 1. Belt of Alpine Plants . . . . | 14,170 |
| 2. Belt of Rhododendrons . . . . | 12,150 |
| 3. Belt of Pines . . . . . | 10,140 |
| 4. Belt of European Dicotyledonous Trees . | 8,100 |
| 5. Belt of Evergreen Dicotyledonous Trees . | 6,120 |
| 6. Belt of Myrtles and Laurels . . . | 4,050 |
| 7. Belt of Tree-ferns and Figs . . . | 2,020 |
| 8. Belt of Palms and Bananas . . . | 0 |

Each of these belts descends towards the level of the sea to the north and south of the equatorial region, and forms a zone encircling the earth; but the absolute width of these zones is variable, owing to their dependence upon isothermal lines, *i.e.*, lines of the same average temperature, rather than on lines of latitude.

Similarly Edward Forbes arranged marine life in nine "homoiozoic belts" (belts of similar life), bounded in the same way by isotherms on either side of the equator. He further divided all seas into five vertical spaces which he called zones, thus:—

1. Littoral zone, the space between high- and low-water mark.

2. Circum-littoral zone, from low-water mark to 15 fathoms.
3. Median zone, from 15 to about 50 fathoms.
4. Infra-median zone, from 50 to about 100 fathoms.
5. Abyssal zone, from 100 to the greatest depth at which life is found (about 1,000 fathoms).

Besides these zonal divisions, depending on climate and depth, there is also a distribution of sea-creatures according to the nature of the bottom, whether rocky, sandy, or muddy, corresponding in a manner to the difference of soil upon land, but having a more marked influence. Thus the assemblage of creatures dredged from a rocky or sandy bottom will differ considerably from those obtained on a muddy bottom, though a few species may be found in all three. Even whole orders of animals, such as the reef-building corals, live only in clear water, and would never therefore be found where sand or mud was being deposited.

Confining our attention to the Mollusca, the following lists will illustrate what has been stated above; the genera mentioned under each head are those which prefer to live on such "bottoms," though some, such as *Tapes*, frequent both rocky and sandy bottoms.

| Rocky. | Sandy. | Muddy. |
|---|---|---|
| Buccinum. | Nassa. | Corbula. |
| Purpura. | Natica. | Lutraria. |
| Litorina. | Cypræa. | Mya. |
| Patella. | Turritella. | Scrobicularia. |
| Arca. | Cardium. | Yoldia. |
| Tapes. | Tellina, | Dentalium. |
| Venerupis. | Donax. | |
| Saxicava. | Mactra. | |
| Pholas. | Solen. | |

**Distribution of Life in Provinces.**—A more complete study of the distribution of plants and animals throughout the world has shown that there is a further limitation of certain species and genera to certain areas or regions, a restriction for which differences of climate, food,

and station are not sufficient to account. Contrast, for instance, the productions of tropical Africa and tropical America; and though there is a certain general similarity between them, in accordance with the similarity of climate, yet the differences are so great that it is clear some powerful influences have been at work to produce the results. The same conclusion would be arrived at by a comparison of the plants of Europe and North America, which are very different, though closely similar soils and climates may be found in both regions.

The various forms of life are, in fact, so distributed over the earth that its surface can be mapped out into geographical regions or provinces to which certain groups of genera are confined. The boundaries of these provinces are sometimes well-marked, especially where any strong natural feature exists to act as a barrier, and prevent migration from one area to another: a chain of lofty mountains, a wide expanse of ocean, or an isthmus of land separating marine provinces, are such natural barriers.

The study of modern marine life is, of course, most useful to the geologist; but space would not allow us to indicate the distribution of the several classes of marine animals, even if full data were available, and it must therefore suffice to select the Mollusca as an example.

In the distribution of the Mollusca, 17 marine provinces, exclusive of the Aralo-Caspian area, are recognized by Dr. S. P. Woodward. These may be grouped as follows:—

1. Arctic zone—the *Arctic* province.
2. Cold Temperate zone—the *Boreal*, *Celtic* and *Aleutian* provinces.
3. Warm Temperate zone—the *Lusitanian*, *Transatlantic*, *Californian* and *Japonic* provinces.
4. Tropical zone—*West African*, *Indo-Pacific*, *Panamic* and *Caribbean* provinces.
5. South Temperate zone—*South African*, *Australian*, *Peruvian* and *Patagonian* provinces.
6. Antarctic zone—the *Magellanic* province.

The Arctic province includes not only the North Polar seas, but the Greenland and North American coasts as far as Newfoundland.

The Boreal and Celtic provinces include the coasts on either side the Atlantic so far south as Massachusetts and the north coast of France. The Aleutian occupies a similar position in the North Pacific.

The Lusitanian province is formed by the shores of the Bay of Biscay, Portugal, N. W. Africa, and the Mediterranean. The Japonic is limited to the Japanese islands. The Californian and Transatlantic, or Pennsylvanian, occupy opposite coasts of the American continent.

The names of the provinces in the tropical zone speak for themselves; as do also those of the South Temperate zone, the Australian including that part of Australia lying south of the tropics and New Zealand.

South America is the only continent which extends into the Antarctic zone; and the Magellanic province includes Tierra del Fuego and part of the coasts of Chili and Patagonia, together with the Falkland Islands.

Very few genera are limited to any one of these provinces, the most specialised being the Australian province to which no less than eight genera are confined. A few genera are specially characteristic of high latitudes, such as *Chrysodomus, Admete, Trichotropis, Yoldia, Cyprina, Glycimeris*. Some are found only in temperate climes, but occur both north and south of the equator, as *Fissurella, Haliotis, Terebratulina, Trophon, Pandora, Panopæa*. Others are essentially tropical as *Conus, Harpa, Oliva, Voluta, Mitra, Cyprœa, Columbella, Spondylus, Plicatula, Perna, Tridacna* and *Crassatella*. There are many curious cases of extended distribution: thus *Mitra*, which has its home in the Indo-Pacific provinces, has one species on the west coast of Africa, several in the Lusitanian province, and one in Greenland. *Voluta*, though generally tropical, has several species at the extremity of South America.

**Some Inferences from the foregoing facts.**—A study of the modern distribution of life, whether in the sea or on the land, shows us that the provinces primarily depend on climate, and exhibit a tendency to arrange themselves in broad belts between the equator and the poles. This arrangement, however, has evidently been interfered with by the disposition of the continents, and the limits of the provinces are further narrowed or extended according

to the union of the seas and continents. The spread of terrestrial life must depend on the present or past continuity of lands, and especially on the connections in an east and west direction: the spread of marine life will depend on the extension of coast lines in the same direction.

The truth of the above remarks is well exemplified by considering the marine provinces on the western coasts of the Old and New Worlds respectively. Along the west coast of the New World we have the simplest possible arrangement of life regions, namely, a linear succession of provinces along a north and south coast line, and depending entirely on differences of climate. These provinces are (1) Aleutian, (2) Californian, (3) Panamic, (4) Peruvian, (5) Magellanic. The narrow isthmus of Panama prevents the union of the Panamic and Caribbean faunas which lie on either side of it; and if the coast of South America did not extend so far south, the Magellanic province would not exist, and the Peruvian would blend into the Patagonian.

Now let us turn to the Old World with its broken coast-line: here the corresponding provinces are (1) Celtic, (2) Lusitanian, (3) West African, (4), South African, (5) (unrepresented). The latitudinal extent of these areas is very different from the American provinces; instead of being limited by a north and south coast line, the Celtic province spreads round England and eastward across the North Sea, the Lusitanian fauna likewise passes through the Straits of Gibraltar and stretches eastward as far as the Mediterranean Sea allows it. The West African is more limited, but the South African occupies eastern as well as western coasts.

It will be instructive next to consider what important effects on the distribution of life would be produced by some very slight changes in the geography of the world. Let us first suppose the isthmus of Panama and the southern extremity of South America to be submerged, and mark what would follow:—the Panamic and Caribbean provinces would no longer be separated: the Magellanic would disappear as a coast province (though some of the species would probably remain on the colder sea-bottoms), and the Peruvian and Patagonian would be merged into a province comparable with the South African.

On the other hand, if in the Old World we imagine England united to France, an isthmus of land raised across the Straits of Gibraltar and the extremity of Africa prolonged southwards, we should then have an arrangement of life-provinces precisely like that which we now find along the west coast of America. The Celtic province would be limited to the west coasts of Britain and France, and the fauna of the North Sea would probably become more distinctly Boreal, the Lusitanian area would be similarly restricted, the Mediterranean becoming an inland sea, and its fauna being gradually differentiated from the Lusitanian; finally the prolonged extremity of Africa would become an Antarctic province comparable to the Magellanic, and would separate the eastern and western shores of south-temperate Africa, thus causing the development of two new provinces like the Peruvian and Patagonian of South America.

The above is not a mere wanton exercise of the imagination, for we know that similar geographical changes have taken place in past times, and that such curtailments and enlargements of life-provinces must have occurred in consequence. We can even trace the operation of some such changes during the later periods of geological history. For instance, we have not to travel very far back in time before we come to a period when England was united to the Continent, and was then inhabited by many large mammalia which have since become extinct. Again, evidence has recently been obtained which tends to show that in early Pliocene times the east and west coasts of England did belong to different life-provinces, in consequence of the union of England with the Continent, very few of the species being common to the deposits in Cornwall and Suffolk.

The farther we go back in geological time the greater differences do we perceive in the distribution of the faunas, and the greater difficulty do we find in determining the limits of the life-provinces; but in comparing the fossils of the different members of the Tertiary and Secondary formations, we must bear in mind that such provinces did undoubtedly exist, and that in tracing the rocks from one district to another, we may at any time pass from the area

of one province into that of another. When we reach the Primary rocks there is some doubt as to the existence of very definite life-provinces, which seem at any rate to have been fewer, and consequently more extensive than those of later periods.

The wide range of certain Palæozoic species suggests that there was a time when the same marine fauna ranged over the whole world, and that it was only as time went on that genera became limited to certain portions of the earth's surface, the modern life-provinces being the outcome of local differentiation, and of the circumstances which have retarded or accelerated the progress of development from time to time.

## CHAPTER II.

### THE ORIGIN AND SUCCESSION OF SPECIES.

**SPECIFIC and Generic Centres.**—The provinces mentioned in the last chapter are founded upon the geographical limitation of families and groups of genera; but single genera and species likewise have their limitations, some having a wide range within the province, others being confined to very small areas.

The facts point unmistakably to the conclusion that both species and genera have originated at certain localities or centres, and have from thence spread in all directions as far as physical conditions permitted. This conclusion was reached long before the publication of Darwin's "Origin of Species," and is entirely independent of the facts adduced in support of Evolution. Edward Forbes strongly insisted on it, and pointed out that genera had centres where their species were abundant and flourishing, just as species had centres where their individuals were most numerous, and that in receding from these centres the individuals in the one case, and the species in the other, diminish in number and vigour till at certain limits they cease to exist.

The significance of these facts, however, is greatly increased by the acceptance of the view urged by Darwin and Wallace, that species are not fixed creations, but highly alterable forms, derived one from another under the influence of external conditions. From the known facts, that variations are constantly appearing among the offspring of known species, and that under favourable conditions some of the variations may be perpetuated, they conclude that the continual "struggle for life" results in a "natural

selection" of the types most fitted to maintain themselves: hence by a "survival of the fittest" varieties may become species, and species by limitation may become genera. "Thus," says Dr. A. Geikie,[1] "the present varied life of the globe may be explained by the accumulation, perpetuation, and increase of differences in the evolution of plants and animals during the whole of geological time. Hence the geological record should contain a more or less full chronicle of the progress of this long history of development."

**Imperfection of the Geological Record.**—That the truth of Dr. Darwin's theory of the origin of species cannot at once be proved, and the complete genealogy of modern genera be constructed from the records of the past, is due to the imperfection of that very geological record which would otherwise contain the obvious proof or refutation of the hypothesis. This imperfection results from two causes, (1) the conditions which limit the entombment and preservation of organic remains, (2) the frequent erosion and destruction of the deposits in which they have been buried.

1. *Conditions of Entombment.*—If we consider the manner in which deposits are now taking place ("Physical Geology," Part I., Chapters IX.-XII.), we shall see that the preservation of organic remains in these deposits is likely to be an exceptional and accidental occurrence. It is not an uninterrupted process likely to ensure the conservation of specimens of the greater number of plants and animals living at any one time, but is, on the contrary, so discontinuous that only a small proportion of any fauna or flora would be entombed in such a way as to be permanently preserved, either in terrestrial or marine deposits.

On land, generations of animals may die and moulder away, shells, bones, and all, without any remains being transported to places where deposits are accumulating. Of the larger animals a few are occasionally buried in bogs or drowned in lakes and rivers, and still fewer are carried down by rivers to the sea. The animals which live in fresh water, and the leaves of plants, stand a better chance of

[1] "Text Book of Geology," first edition, p. 624.

preservation in those parts of the country where lacustrine and fluviatile deposits are being formed; but these purely freshwater beds occupy but small areas, and are particularly liable to subsequent destruction; so that as a rule our knowledge of the terrestrial and fluviatile fauna of any period is derived from the specimens which were carried down the streams during floods, and were buried in the estuarine deposits at the mouths of large rivers.

The creatures which inhabit the sea have a much better chance of being preserved as fossils, since deposits of one kind or another are constantly being formed over large areas of the sea-bottom, especially where subsidence is in progress. Yet even among marine forms of life there are many which would only rarely be entombed: those animals, for instance, which live on rocky shores and in clear water would not be preserved except where deposits of limestone were in process of formation. The majority of the creatures embedded would be those which lived on sandy and muddy bottoms, together with some of the free-swimming forms which moved through the water above.

Lastly, of the creatures so embedded only a small proportion would ultimately remain; those, namely, which possessed hard structures capable of fossilization after the softer parts had decayed and disappeared. The following table shows at a glance which kinds of animals, out of all those which live in the sea, would be likely to leave memorials behind them and which would perish without leaving any trace of their existence.

| Classes. | Groups with stable structures. | Perishable groups. |
|---|---|---|
| Protozoa. | Foraminifera.<br>Radiolaria. | |
| Hydrozoa. | Spongida.<br>Sertularida.<br>Graptolites. | Hydroida (except Sertularida).<br>Siphonophora.<br>Discophora. |
| Actinozoa. | Some Zoantharia.<br>Some Alcyonaria. | Zoantharia (some).<br>Alcyonaria (some).<br>Ctenophora. |
| Echinodermata. | All orders. | None. |

| Classes. | Groups with stable structures. | Perishable groups. |
|---|---|---|
| Scolecida. | None. | All orders. |
| Annelida. | Tubicola, and the horny jaws of other orders. | Few traces except of Tubicola. |
| Arthropoda. | All Crustacea. | |
| Molluscoida. | Polyzoa. Brachiopoda. | None. |
| Mollusca. | Lamellibranchiata. Gasteropoda (almost all). Pteropoda. Cephalopoda. | Nudibranchiata. |
| Ascidians. | None. | All orders. |
| Pisces. | Teeth, bones and scales. | None. |

The proportion of those remains which would otherwise be preserved is further diminished by the subsequent destruction of some of them owing to the percolation of water through sandy deposits; the embedded calcareous structures being often completely dissolved and removed, though it sometimes happens that the calcite is replaced by silica or some other mineral, and the form of the structure is then equally well preserved.

From all these causes it results that the assemblages of fossils which are preserved in the rocks include only a small proportion of the total number of species which must actually have lived during the periods represented by the different systems of strata. Thus we know that several orders of insects were in existence as early as the Carboniferous Period, yet the remains of insects are among the rarest of fossils, and only occur at a few distant horizons throughout the subsequent series of rocks.

2. *Absence and Destruction of Fossiliferous Deposits.*—There is another set of causes equally potent in rendering the geological record a very imperfect one. Continental land has existed from the earliest times, and in its neighbourhood land and sea have constantly been changing places; in other words, areas of deposition have again and again become areas of non-deposition, for the formation of marine

deposits must necessarily cease when any tract of the sea bottom is raised into land. Over such spaces, therefore, no records of contemporary marine life could possibly be preserved, and when parts of such land came at last to be submerged again, so that the rocks of which they consisted were covered up by new deposits, the interval between the older and newer strata must represent a gap in the history of the marine life, great in proportion to the length of time during which the area existed as land. It is true that intervening deposits may have been formed elsewhere, but the fact remains that over that particular space the record is imperfect—geographical changes may have taken place, involving the extinction of some species and genera, the migration of others, the introduction of fresh species into the surrounding seas, and perhaps the development of many new varieties and species along the coast lines.

Thus to anyone who for the first time examined and compared the contents of the beds above and below the plane of such a break or unconformity in the succession of rocks, and who was unacquainted with the principles here laid down, it might well seem that he had proof of some great convulsion, involving the total and sudden destruction of the older races of animals, and paving the way for the creation of an entirely new assemblage of beings. But we can now see that the changes were the result of a natural and gradual succession of events, and that the sudden change from one set of rocks to another is only an instance of the imperfection of our record.

Again, when any tract is raised into land, there is not only an absence of deposition, but there commences an actual destruction of the records previously accumulated. In the first place, as the rising land passes through the plane of the sea-level, it is exposed to the erosion of the waves, and if the latest deposits are not of any great thickness, and the process of elevation is not very rapid, the probability is that only small portions will escape destruction. These portions will remain for a time as plains, marsh lands, and raised beaches; but as elevation continues, they will be brought gradually under the influence of atmospheric agencies, and exposed to continual wear and tear so long as they remain above the sea.

It follows, therefore, that only deposits of considerable thickness will survive the attacks of destructive agencies, and remain to form a permanent part of the earth's crust, but thick deposits cannot be accumulated in shallow seas, *which are the most favourable to life*, so long as the sea-bed remains stationary or is being elevated. Thick formations can only be accumulated in areas where constant subsidence has been in progress, or where the shore originally shelved rapidly into deep water, as off the coast of the Riviera. In the latter case, the sediment will be rapidly accumulated, and will not contain so many or such varied forms of life; but under the former conditions, if the supply of sediment was sufficient to keep the sea shallow and to embed the organic remains, a formation rich in fossils, and thick enough, when upraised, to resist erosion, would be formed. We must, therefore, conclude with Darwin, "that nearly all our ancient formations, which are throughout the greater part of their thickness *rich in fossils*, have thus been formed during subsidence."[1] He adds, "Since publishing my views on this subject in 1845, I have watched the progress of Geology, and have been surprised to note how author after author, in treating of this or that great formation, has come to the conclusion that it was accumulated during subsidence."

**The Succession of Life-forms.**—This conclusion that most of our great fossil-bearing formations have been deposited during subsidence has a very important bearing on the question before us, viz., whether the rocks are likely to contain the remains of an uninterrupted succession of species, or whether the record is more or less incomplete. I do not hesitate to quote some further instructive remarks from Darwin's celebrated treatise:—

"During periods of elevation the area of the land and of the adjoining shoal parts of the sea will be increased, and new stations will often be formed—all circumstances favourable, as previously explained, for the formation of new varieties and species; but during such periods there will generally be a blank in the geological record. On the other hand, during subsidence, the inhabited area and

[1] "Origin of Species," sixth edition, p. 273.

number of inhabitants will decrease (excepting on the shores of a continent when first broken up into an archipelago), and consequently during subsidence, though there will be much extinction, few new varieties or species will be formed ; and it is during these very periods of subsidence that the deposits which are richest in fossils have been accumulated."[1]

"If, then, there be some degree of truth in these remarks, we have no right to expect to find in our geological formations an infinite number of those fine transitional forms, which on our theory have connected all the past and present species of the same group into one long and branching chain of life. We ought only to look for a few links, and such assuredly we do find."[2]

Again, after mentioning the two facts, (1) that the assemblage of fossils found in any formation has a general character intermediate between the assemblages above and below ; and (2) that the fossils from two consecutive formations are far more closely related to each other than the fossils from two more remote formations; he observes :[3]—"On the theory of descent, the full meaning of the fossil remains from closely consecutive formations being closely related, though ranked as distinct species, is obvious. . . . We ought not to expect to find in any one, or in any two, formations all the intermediate varieties between the species which occurred at the commencement and the close of those formations ; but we ought to find, after intervals very long as measured by years, but only moderately long as measured geologically, closely allied forms, or, as they have been called by some authors, representative species ; and these assuredly we do find. We find, in short, such evidence of the slow and scarcely sensible mutations of specific forms as we have the right to expect."

In spite, therefore, of the imperfection of the record, the known succession of life-forms does give very great support to the theory of Evolution. Every succeeding fossil assemblage contains not only a larger number and greater variety of forms, but also some which are distinctly more

[1] Op. cit., p. 275. [2] Op. cit., p. 282. [3] Op. cit., p. 307.

specialized and more advanced in organization. It is an acknowledged fact that many of the more ancient forms of life were what are termed "comprehensive types," *i.e.*, types which present structural resemblances to two or more different orders, or classes of creatures, which are now completely differentiated from each other. In many cases also ancient animals resemble in some respects the embryos of the more recent animals belonging to the same classes.

Beyond all this there can be traced a distinct and decided progress in the types of life as we ascend the geological scale. It is true that in the earliest fauna yet known we start with a number of more or less specialized invertebrate types, but the more highly organized orders of Gasteropods, Cephalopods, Crustacea, and Echinoderms do not appear till later periods; Fish are not known earlier than Silurian times; Amphibia commence in the Carboniferous; Reptiles in the Dyas and Trias; Birds in the Jurassic; Marsupial Mammals in the Trias; other orders date from the Eocene only. The following tables present these facts in a more detailed form:—

RANGE OF CŒLENTERATA, ECHINODERMATA, AND CRUSTACEA.

| | Cambrian. | Ordovician. | Silurian. | Devonian. | Carboniferous. | Dyassic. | Triassic. | Jurassic. | Cretaceous. | Hantonian. | Icenian. | Recent. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Actinozoa.** | | | | | | | | | | | | |
| Rugosa | | × | × | × | × | × | | | | | | |
| Tabulata | | × | × | × | × | × | × | — | × | — | — | × |
| Tubulosa | | × | × | × | × | | | | | | | |
| Perforata | | × | × | × | — | — | — | × | — | × | — | × |
| Aporosa | | | | | | | × | × | × | × | × | × |
| Alcyonaria | | × | × | × | × | — | — | — | × | × | — | × |
| **Hydrozoa.** | | | | | | | | | | | | |
| Graptolitidæ | × | × | × | | | | | | | | | |
| Sertularidæ | | × | × | — | — | — | — | — | — | — | — | × |
| Milleporidæ | | × | × | × | × | × | — | × | × | — | × | × |
| Seriatoporidæ | | | | × | × | — | — | — | — | — | — | × |
| **Echinodermata.** | | | | | | | | | | | | |
| Edrioasteridea | | × | | | | | | | | | | |
| Cystoidea | × | × | × | × | | | | | | | | |
| Blastoidea | | | × | × | × | | | | | | | |

| | Cambrian. | Ordovician. | Silurian. | Devonian. | Carboniferous. | Dyasic. | Triassic. | Jurassic. | Cretaceous. | Hantonian. | Icenian. | Recent. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Echinodermata. | | | | | | | | | | | | |
| Crinoidea | × | × | × | × | × | × | × | × | × | × | × | × |
| Asteroidea | | × | × | × | × | × | × | × | × | × | × | × |
| Ophiuroidea | | × | × | × | × | × | × | × | × | × | × | × |
| Echinoidea | | | | | | | | | | | | |
| Perischoechinidæ | | | × | × | × | | | | | | | |
| Neoechinidæ | | | | | | | × | × | × | × | × | × |
| Crustacea. | | | | | | | | | | | | |
| Trilobita | × | × | × | × | × | | | | | | | |
| Merostomata | | | × | × | × | — | — | × | — | — | — | × |
| Phyllopoda | × | × | × | × | × | × | — | × | × | — | — | × |
| Ostracoda | × | × | × | × | × | × | × | × | × | × | × | × |
| Isopoda | | | | × | × | — | — | × | × | × | — | × |
| Amphipoda | | | × | — | × | × | — | × | — | — | — | × |
| Cirripedia | | | × | — | — | — | — | × | × | × | × | × |
| Stomapoda | | | | | × | — | — | × | × | × | — | × |
| Decapoda | | | | | | | | × | × | × | × | × |

## RANGE OF MOLLUSCA AND MOLLUSCOIDA.

| | Cambrian. | Ordovician. | Silurian. | Devonian. | Carboniferous. | Dyasic. | Triassic. | Jurassic. | Cretaceous. | Hantonian. | Icenian. | Recent. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cephalopoda. | | | | | | | | | | | | |
| Dibranchiata | | | | | | | | × | × | × | × | × |
| Tetrabranchiata | × | × | × | × | × | × | × | × | × | × | × | × |
| Gasteropoda. | | | | | | | | | | | | |
| Siphonostomata | | | | | | | | × | × | × | × | × |
| Holostomata | | × | × | × | × | × | × | × | × | × | × | × |
| Opisthobranchiata | | | | | × | — | — | × | × | × | × | × |
| Pulmonifera | | | | | × | — | — | × | × | × | × | × |
| Heteropoda | × | × | × | × | × | — | × | — | × | — | — | × |
| Pteropoda | × | × | × | × | × | — | — | — | — | × | × | × |
| Lamellibranchiata. | | | | | | | | | | | | |
| Asiphonida | × | × | × | × | × | × | × | × | × | × | × | × |
| Siphonida | | × | × | × | × | × | × | × | × | × | × | × |
| Brachiopoda. | | | | | | | | | | | | |
| Articulata | × | × | × | × | × | × | × | × | × | × | × | × |
| Inarticulata | × | × | × | × | × | × | — | × | × | × | × | × |
| Polyzoa | ? | × | × | × | × | × | — | × | × | × | × | × |

It is interesting to note that the Pteropods, which appeared before the Gasteropods, are really permanent representatives of the larval stage of the latter. The apparent absence of Pteropods from the Chalk is difficult to understand.

Of the siphonate Lamellibranchs, only three families, *Cardiadæ*, *Cyprinidæ*, and *Anatinidæ*, occur in the Palæozoic era, no representatives of the other twelve families being known below the Jurassic strata.

RANGE OF THE VERTEBRATA.

| | Cambrian. | Ordovician. | Silurian. | Devonian. | Carboniferous. | Dyassic. | Triassic. | Jurassic. | Cretaceous. | Hantonian. | Icenian. | Recent. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pisces. | | | | | | | | | | | | |
| Elasmobranchs | | | × | × | × | — | × | × | × | × | × | × |
| Ganoidei | | | | × | × | × | × | × | × | × | — | × |
| Dipnoi | | | | × | × | — | × | — | — | — | — | × |
| Teleostei | | | | | | | | | × | × | × | × |
| Amphibia. | | | | | | | | | | | | |
| Urodela | | | | | | × | × | — | — | — | — | × |
| Labyrinthodonta | | | | | × | × | × | | | | | |
| Batrachia | | | | | | | | | | × | — | × |
| Ophiomorpha | | | | | | | | | | | | × |
| Reptilia. | | | | | | | | | | | | |
| Dinosauria | | | | | | | × | × | | | | |
| Pterosauria | | | | | | | | × | × | | | |
| Dicynodontia | | | | | | | × | | | | | |
| Crocodilia | | | | | | | | × | × | × | × | × |
| Ichthyosauria | | | | | | | ? | × | × | | | |
| Plesiosauria | | | | | | | ? | × | × | | | |
| Lacertilia | | | | | | × | × | × | × | × | ? | × |
| Ophidia | | | | | | | | | | × | × | × |
| Chelonia | | | | | | | | × | × | × | ? | × |
| Aves. | | | | | | | | | | | | |
| Saururæ | | | | | | | | × | | | | |
| Odontornithes | | | | | | | | | × | | | |
| Ratitæ | | | | | | | | | | × | × | × |
| Carinatæ | | | | | | | | | | × | × | × |
| Mammalia. | | | | | | | | | | | | |
| Marsupialia | | | | | | | × | × | — | × | × | × |
| Edentata | | | | | | | | | | | × | × |
| Carnivora, &c. | | | | | | | | | | × | × | × |
| Bimana | | | | | | | | | | | × | × |

## CHAPTER III.

### THE CORRELATION AND CLASSIFICATION OF ROCKS ON PALÆONTOLOGICAL PRINCIPLES.

WE are now in a position to indicate some of the limitations referred to on p. 3, as regards the use of fossils in correlating the rocks of separate districts or countries, and to discuss the comparative value of palæontological and stratigraphical evidence as principles of classification.

**Synchronism and Homotaxis.**—It was stated in Chapter I. that when two districts are physically separated from one another we have to rely entirely on community of fossils in comparing the rocks of the one with those of the other; and if the rocks so compared were deposited originally within the limits of the same life-province, the groups which contain similar assemblages of species may safely be regarded as contemporaneous.

It is true that when we are dealing with a group of stratified rocks, made up partly of limestones and partly of shales and sandstones, we find that the assemblage of fossils in the limestones is different from that in the shales, and the fossils in the latter are different from those in the sandy sediments, because different creatures would live on the sea-bottoms where such different deposits were being laid down. Consequently, it might be thought that if a formation consisted in one district entirely of shale or limestone, and in another entirely of sandstone, the two sets of strata would contain such different assemblages of fossils that they might, on this principle, be regarded as belonging to two different systems, while in reality they were as nearly as possible contemporaneous. But, as a

matter of fact, it is seldom that a natural group of rocks consists so entirely of one kind of sediment; the probability is that some beds of shale would be found in both districts, and that these shales, by their community of fossils, would establish the synchronism of the rocks with which they were associated. Moreover, there are frequently a few species which are not so restricted in habitat, but occur both in the shaly and sandy sediments alike, having a wide range both in space and time; and such forms greatly assist in the work of correlation.

To take an example, no one would hesitate to correlate the members of the Ordovician and Silurian systems in North Wales and the Lake District by means of the fossils they contain, because there is every reason to suppose that the two districts formed part of the same province during those periods. Similarly the members of the Lower Cretaceous series in the Isle of Wight and in the Weald may be correlated with some degree of exactitude; but the same group of beds in Lincolnshire contains such a different set of fossils that it obviously belonged to a different life-province, and it is impossible to indicate the exact equivalents of the several members of the southern series.

Again, when we come to compare districts at a still greater distance from one another—as, for instance, Wales and Bohemia, Sussex and the South of France, or England generally with North America—we find that there is certainly a general resemblance in the vertical succession of faunas which have flourished in the respective areas, *i.e.*, the rock-series in each country can be divided into groups, which are characterized by the presence of the same or closely allied genera; but the species are different, and it would be a mistake to conclude that formations containing assemblages of the same genera in countries so far apart were contemporaneous in the same sense as the members of the Silurian series in Wales and Cumberland are contemporaneous.

A group of species originating in one locality, and spreading along the coasts of a continent, would take a long time to travel from Europe to America, even if there were continuous coast lines. Sometimes their progress would be arrested for a time, until physical or geographical

changes allowed them to advance; at other times they would make their way by accommodating themselves to varying conditions, and by throwing out collateral varieties. The date of their first appearance in one part of the world would be very much in advance of their arrival in the other; so that the fact of two distant formations containing fossils of closely allied species can be no proof of their being really contemporaneous.

Again, a portion of a life-province may be isolated from the remainder by the submergence or upheaval of land; and while the old fauna might remain with little change in the portion so isolated, rapid changes might take place in the other parts of the area, resulting in the development of a very different fauna. Such occurrences have, no doubt, often happened in past times, and have caused the rapidity of evolution to vary greatly in different parts of the world. The Australian life of the present day, for instance, especially the terrestrial life, has a character similar to that which prevailed in Europe and Asia during the Jurassic period; and it is probable that none of the European Tertiary animals ever found their way into the Australian region. Again, the fauna of the modern Atlantic ooze recalls, in many respects, that of the European Chalk; and it is not unlikely that some of the deep-sea forms are direct descendants of the Cretaceous species; these creatures having survived in the Atlantic while they were displaced from the European area by the upheaval of the continent at the close of the Cretaceous period. These facts must be remembered when the rocks of distant countries are correlated by the fossils which they contain.

It is certain, however, that in every part of the world the geological sequence discloses the same general succession of life-forms. The progress of development may have been retarded here and accelerated there; but the successive fossil assemblages are similar to one another, and the order in which they occur is the same all over the world. We never find a Carboniferous fauna antedating a Silurian or Devonian fauna, though we may find the first succeeding the second without the presence of the intermediate Devonian assemblage. This common order of succession has been termed *Homotaxis*, and the Silurian system of

Britain is spoken of as *homotaxial* with the Silurian of America; even the larger subdivisions of the one may be paralleled with those of the other, as homotaxial equivalents or representatives, so that we may speak of Valentian rocks in both countries, understanding by this that the groups are homotaxial equivalents, and not absolutely coeval formations.

To sum up the preceding observations, the occurrence of the same assemblage of species at different localities may be taken as evidence that the beds containing them are of the same age, and belong to one and the same formation. Again, a knowledge of the general succession of generic forms enables us to fix the relative age of any set of fossils, and, consequently, the homotaxial position of the beds containing them. In other words:

1. Assemblages, having many species in common, may be regarded as contemporaneous.
2. Assemblages, having many genera in common, may be regarded as homotaxial equivalents.

**Palæontological Zones.**—The first of the above propositions admits of very minute application in the case of certain Neozoic formations, where the conditions controlling the evolution and distribution of life appear to have changed more rapidly than the physical conditions affecting the lithological constitution of the deposits. So quickly is one group of species succeeded by another that palæontological divisions may be made in a thick formation of clay or limestone, in which there is little variation of lithological character. These divisions are called *zones*, and they can sometimes be traced over a large district, but of course they will not extend beyond the limits of the marine area or province in which the particular formation was deposited. It is customary to designate zones by the name of some prevalent and characteristic fossil, which is selected for its index, as, for instance, the zone of *Ammonites planorbis*.

**Establishment of Geological Systems.**—A system may be defined as a consecutive series of strata deposited during the continuance of a certain set of generic forms in any given part of the world. As a rule, this also implies

the continuance of certain geographical conditions, during which the physical changes were not very great or extensive. Such conditions are found in the gradual subsidence of any area, and consequently some have defined a system as the series of deposits formed during one complete oscillation of any region of the earth's crust, the oscillation comprising a downward and an upward movement, so that every system should begin with shore deposits and be terminated by a plane of unconformity. It will presently be seen, however, that such a definition cannot be accepted.

The number of systems into which the geological series should be divided, and the place of the divisional lines which separate them, are points requiring some consideration, because they involve certain principles of classification. These lines are often drawn where natural breaks occur in the sequence of the strata, indicating the lapse of some length of time, and the occurrence of some considerable changes in physical geography. For the existence of such breaks two kinds of evidence are admitted—(1) Palæontological, (2) Stratigraphical.

1. *Palæontological Evidence.*—A sudden change of fauna in passing upward from one formation to another is often regarded as indicating a period of non-deposition, and therefore a greater or less break in the succession; but unless this coincides with a physical break or unconformity, the mere fact of such a change does not necessarily prove any great lapse of time. The change may be caused in several ways, either by rapid depression, by a sudden immigration of new forms, or by elevation with or without continuous deposition.

It is conceivable, for instance, that rapid depression, causing a considerable increase in the depth of the water, and removing the area farther away from the coast line, would produce what has been termed a palæontological break in a comparatively short period of time, and without any discontinuity of deposit. The beds below a certain plane would embed the remains of a shore fauna, while those above it would contain a deep-water assemblage, which might be very different even if the deposits were of similar lithological character. Depression, by the submergence of barriers, may also cause much more extensive

changes; we have only to consider what would result from the submergence of certain existent isthmuses, such as those of Panama and Suez, to realize what must have repeatedly happened in the past. The balance of life in both provinces would be altogether disturbed and upset, resulting in the extinction of some forms, the inter-migration of others, and the development of some new varieties and species.

Moreover, an alteration in the physical geography of one area may indirectly, but very greatly, affect the climate and life of another distant area: thus, if the isthmus of Panama were now to be submerged, the Gulf-stream would probably be diverted from its present course, and the result would be an immediate refrigeration of the British climate and a consequent immigration of Boreal and Arctic species into the Celtic province. Conversely, if after some length of time the barrier were again upraised, and the warm current again deflected into its present course, the climate would be ameliorated, Boreal forms would disappear, and a more southern assemblage would once more occupy the area.

Elevation of the sea-bottom will produce similar direct changes to those caused by depression; a deep sea area, where deposition has been very slow, may by elevation be brought nearer to a coast line, and beds containing a deep-sea fauna may be succeeded immediately by others more rapidly accumulated, and embedding a shallow water assemblage. The change of life in such a case would be great, but the lapse of time would not be correspondingly long.

If, however, elevation is continued till the area is raised above the sea-level, and remains for a time as a land surface, then a plane of erosion will be formed, and the change of fauna will be accompanied by stratigraphical discontinuity. The break then may be very considerable, but it may or may not coincide with the epoch of change from one fauna to another in an adjacent area of subsidence.

The evidence of palæontological breaks must therefore be used cautiously; no one, for instance, would think of regarding the Lower and Middle divisions of the Chalk as belonging to two different formations separated by a great interval of time, yet the palæontological break between

them is considerable, for out of 102 species collected in the Lower Chalk of France, and 83 species from the Middle Chalk, only 15 are yet known to pass from one to the other.

Notwithstanding this, it is true that the continuity of deposition may outlast the duration of a certain fauna; and it may become necessary to draw a line between two faunas of systematic importance in the midst of a conformable series of strata; in such a case it will naturally be drawn where the greatest palæontological break occurs. In other words, a life-assemblage, characteristic of one period in the world's history, may continue to inhabit any area until such changes occur as to cause the introduction of an assemblage which has been gradually developed outside that area, and these changes may take place with or without interruption of deposition in that particular area.

2. *Stratigraphical Evidence.*—The nature of stratigraphical breaks or unconformities was explained in the first volume (Part II., Ch. IX.), and in the present connection we have to deal only with their relative importance and value in classification. The most complete and satisfactory measure of any unconformity is the thickness of strata which were deposited in other areas during the time represented by the gap between the two unconformable formations.

It is not every unconformity which is of sufficient importance to form a plane of division between two systems. Thus there is unconformity between the Bunter and Keuper divisions of the Triassic system, and there is an unconformity between the Inferior Oolite and the Great Oolite series in Lincolnshire; but in each case the beds above and below the break are included in the same system on palæontological grounds, and the thickness of the beds which are elsewhere intercalated between representatives of each group is not very great.

A break which is represented elsewhere by several thousand feet of rock, implies the lapse of a considerable period, and being always accompanied by a great change in the fossils, might be taken as a line of division between two systems. But if systems were to be rigidly limited by

physical unconformities, and defined as a series of beds formed during a complete oscillation of downward and upward movement, the classification of the rocks in one area will break down when applied to those of other districts, because the gaps will occur at different horizons in different areas.' Thus in Britain alone three different classifications at least would be required for the Primary rocks, as the following columns will show, a —— being taken to mean a break or unconformity.

| Wales. | Scotland. | Ireland. |
|---|---|---|
| Carboniferous. | Carboniferous. | Carboniferous. |
| Upper O.R.S. | Upper O.R.S. | Upper O.R.S. |
| Middle O.R.S. | —— | —— |
| Lower O.R.S. | Lower O.R.S. | Lower O.R.S. |
| Silurian. | Silurian. | Silurian. |
| —— | —— | —— |
| Ordovician. | Ordovician. | Ordovician. |
| —— | —— | —— |
| Cambrian. | Cambrian. | Cambrian. |

Thus, if we adopted the arrangement warranted by the stratigraphical breaks which occur in Wales, we should have two separate systems, and two only, for there is a general conformity between the Cambrian and Ordovician, and from the Silurian to the Carboniferous. In Scotland, however, there are two breaks, one between the Cambrian and Ordovician, and another between the two members of the Old Red Sandstone, so that we should be obliged to recognize three separate systems. Again, when, if we pass into Ireland, we find no less than three breaks in different parts of the country, which would involve a further remodelling of the classification, we are, in fact, reduced to the necessity of falling back on palæontological evidence, which forces us to acknowledge the existence of five separate systems, the Old Red Sandstones being equivalent to the Devonian.

As in this case, so also in others, a classification founded on physical breaks may be conveniently used for a limited district, and until further knowledge is acquired; but the breaks in the succession are certain to be filled up elsewhere by transitional beds, and as these may be of systematic value, we must always be prepared for the possible

intercalation of another system between any two groups that are divided by a decided unconformity.

In brief, it must be admitted that unconformities are *geological accidents*, and if our classification and nomenclature are to be applicable to any large section of the earth's crust, they must be based, not on stratigraphical, but on palæontological facts. The Ordovician, Devonian, and Jurassic are systems so established; and, in process of time, as our knowledge becomes more and more complete, it is probable that the number of systems will be finally determined in the same manner. They will always be more or less arbitrary divisions, since it will be difficult to say what number of peculiar genera would entitle a series of beds to the rank of a system; but a general agreement will doubtless be reached in time. Meanwhile the student will do well to regard our present classification as provisional, and to remember that, though divisional lines must be drawn somewhere, passage beds and transition groups are of frequent occurrence in nature.

He must also be prepared to find that systems founded on the differences in successive faunas will not include anything like equal thicknesses of rock. If, as appears most probable, the differentiation of species and the development of higher forms has progressed in a constantly increasing ratio, it is clear that the time-value of systems based on such changes will become less and less as we approach modern times. It is certainly a fact that the same forms of life extend through a much greater thickness of rock in the earlier than in later geological times; and there is no reason for supposing that the production of rocks went on more rapidly (at any rate during later Palæozoic periods) than at the present time; limestones must always have been of slow and gradual growth, and yet the persistence of species through the Carboniferous Limestone series is truly remarkable, while the limestones of the Jurassic and Cretaceous periods, though of far less thickness, are divisible into numerous palæontological zones or belts, each having many species which do not appear in the next. The changes in the forms of life inhabiting any marine area being thus more rapid in later geological times, an equal amount of change would naturally be accomplished in less

time, and consequently, if systems are to be measured by palæontological difference, the newer systems must include less thicknesses of rock.

But even when allowance is made for this, it is impossible to regard the divisions of Tertiary time introduced by Sir Ch. Lyell and given on p. 5 as being of the same relative importance as the systems of older date with which they are usually ranked. Even the Eocene, as understood by Lyell, was not of the same palæontological value as Cretaceous or Silurian, while the Miocene and Pliocene are still less entitled to rank with such systems. The author has elsewhere[1] suggested that the Eocene and Oligocene should be united and ranked as a system of the first order under the name of *Hantonian*, from their typical development in Hants and the Isle of Wight; the older names being, of course, retained for two subdivisions of rank equal to that of the Bunter and Keuper divisions of the Trias.

The Miocene, Pliocene, and Pleistocene will naturally fall into a second system for which the name of *Icenian* may be employed, as the British tribe of Iceni inhabited the eastern districts where the typical deposits of the two latter groups occur in Britain.[2] The Miocene is there absent, but may be included in the same system or ranked as a transition group.

Systems are divided into sections or formations, which are usually denominated as Upper, Middle, and Lower, unless any special names have been proposed for them. These sections are again divided into stages or groups, to which local names are generally given, and these again into sub-groups, which are often divisible into zones.

The following is a tabular view of the systems, twelve in number, which will be adopted in this volume, together with their subdivisions of the first and second order.

[1] See "Geol. Mag.," Dec. 3, vol. ii. p. 293, from which some of the above is reproduced.

[2] The name *Icenian* was proposed by S. P. Woodward, in his "Manual of the Mollusca" (1851), as a synonym for the Pliocene.

| Systems. | Primary Divisions. | Groups or Stages. |
|---|---|---|
| ICENIAN. | Pleistocene. | Recent deposits. Raised beaches and Valley gravels. Glacial deposits. |
| | Pliocene. | Forest Bed, Norwich Crag, Red Crag, and White Crag. |
| | Miocene. | None in Britain. |
| HANTONIAN. | Oligocene. | Upper (wanting in Britain). Middle, Hempstead and Bembridge Beds. Lower, Headon Beds. |
| | Eocene. | Bagshot and Barton beds. London Clay. Lower London Tertiaries. |
| CRETACEOUS. | Upper. | Chalk: Upper. Middle. Lower. Upper Greensand and Gault. |
| | Lower. | Vectian or Lower Greensand. Wealden and Neocomian. |
| JURASSIC. | Upper. | Purbeck and Portland beds. Kimmeridge Clay. Corallian and Oxford Clay. |
| | Middle. | Great Oolite series. Inferior Oolite series. |
| | Lower. | Upper Lias. Marlstone and Sands. Lower Lias and Rhætic ? |
| TRIASSIC. | Keuper. | Marls, Sandstones, and Conglomerate. |
| | Muschelkalk. | Absent in Britain. |
| | Bunter. | Upper Sandstone. Pebble Beds. Lower Sandstone. |
| PERM. | Dyas. | Magnesian Limestone and St. Bees Sandstone. Marl Slates and Penrith Sandstone. |

| Systems. | Primary Divisions. | Groups or Stages. |
|---|---|---|
| CARBONIFEROUS. | Upper. | Coal-measures (Upper. Middle. Lower.) |
| | | Millstone Grit. |
| | Lower. | Carboniferous Limestone Series or Bernician. |
| | | Tuedian and Calciferous Series. |
| DEVONIAN. | Upper. | Pickwell Down and Petherwin Beds. |
| | Middle. | Mortehoe Slates and Ilfracombe Beds. |
| | Lower. | Hangman Grits and Lynton Beds. |
| SILURIAN. | Clunian. | Tilestones and Downton Sandstone. |
| | | U. Ludlow and Aymestry Limestone. |
| | Salopian. | Lower Ludlow. Wenlock Limestone, Shale, and Woolhope Limestone. |
| | Valentian. | Tarannon Shales. |
| | | May Hill Sandstone. |
| | | Lower Llandovery. |
| ORDOVICIAN. | Upper. | Hirnant Beds. Ashgill Shales. |
| | | Bala and Coniston Limestones. |
| | | Slates and Sandstones. |
| | Middle. | Flags with *O. Buchii*. |
| | | Shales with *As. tyrannus*. |
| | | Llanvirn series. |
| | Lower. | Arenig, Upper and Lower. |
| CAMBRIAN. | Upper. | Tremadoc slates. |
| | | Lingula flags (Dolgelly group. Ffestiniog group. Maentwrog group.) |
| | Lower. | Menevian (Upper and Lower). |
| | | Harlech group (Upper and Lower. |
| ARCHÆAN, or, PRE-CAMBRIAN. | | |

**Nomenclature.**—There is little difficulty about the names of the smaller rock-groups, such as chiefly consist of one kind of sediment, and are more or less local in their

occurrence. These are usually named after the place where they were first studied, or where they can be best examined in good natural sections;—thus we have the Wenlock Limestone, Coniston Grits, Bradford Clay, Tremadoc Slate, &c.: others are named from the prevalence of some particular fossil, as *Lingula* Flags, *Cardita* Beds, *Nummulite* Limestone, and the numerous zones or bands of rock which are characterized by the presence of some particular species, such as the Ammonite zones in the Lias: other names again are lithological terms, as the Gault, the Cornbrash, the Marlstone, the Millstone Grit; each of these being named from the particular kind of rock composing the formation, and being that rock *par excellence* in the district where it occurs, although elsewhere there may be other marlstones and other grits from which millstones could be made.

When we deal with larger groups of strata there is more difficulty and more need of explanation. Such names as Old Red Sandstone, Carboniferous, and Cretaceous are used in a far wider sense than their mere lithological signification. These names were originally given to certain British formations, in which the most conspicuous elements were respectively red sandstone, beds of coal, and chalk; but they have since acquired a chronological meaning, and are used as systematic names for the periods of time during which the rocks were formed. Some of them have also been adopted in other countries for rock-groups, which occupy the same relative place in the geological succession.

The Cretaceous system then includes, not only the Chalk and its associated beds in the west of Europe, but all the rocks which were formed during the same period of the earth's history. Elsewhere, therefore, as in North America, the system may consist of sandstones, shales, and coal-seams, without a bed of real chalk in it.

So the Carboniferous system means that system of strata of which the *British* Coal Measures form an integral part, but which includes several other rock-groups, all united by a community of fossils. It is these fossils, and not the occurrence of coal-seams, which are the criterion of the so-called Carboniferous period, for, as above mentioned, in America there are coals of Cretaceous age. In the same

way, when we speak of the Carboniferous Limestone series, we do not mean a group which everywhere consists of limestone, but one to which the great Carboniferous Limestone belongs; when traced northward through England, this limestone is found to split up into separate beds, which finally become subordinate to thick masses of sandstone and shale.

The Old Red Sandstone is a particularly awkward and unsatisfactory name for an important group of rocks. It is supposed to be the freshwater or estuarine equivalent of the Devonian, and was originally applied to a series in which red sandstones predominated, and was called *old* because it lay beneath the Carboniferous rocks, above which came another group of similar red sandstones. The latter were formerly termed New Red Sandstone, but this name has been superseded by a less cumbrous nomenclature, and it is to be hoped that "Old Red Sandstone" also will soon be replaced by a better name. As Mr. Jukes observed more than twenty years ago,[1] "it is avowedly a provisional designation, just exactly as the names of all the great groups of stratified rocks are provisional. They are temporary names adopted for present purposes, and have grown into use, and will continue to be used until they are superseded by more appropriate terms, which increasing knowledge only can show to be more appropriate."

In many respects those names which have a geographical or historical origin are the most satisfactory—names taken from those of towns, rivers, mountain ranges, provinces, or the ancient races which inhabited such provinces; as Neocomian (from the Roman name of Neuchatel), Jurassic (from the Jura range), Wealden (from the Weald), Cambrian (from the Roman name of North Wales), Silurian (from the tribe of the Silures). These will probably remain as permanent names for the groups and systems to which they are applied.

[1] "Manual of Geology," second edition, 1862, p. 429.

# PART V.

## HISTORICAL GEOLOGY.

*Being a Historical Account of the Rock-groups which compose the Crust of the Earth beneath the British Islands, their Fossil Contents, and the Conditions under which they were formed.*

# CHAPTER I.

## Azoic Era—Archæan or Pre-Cambrian Systems.

THE geological history of Britain opens with a chapter the pages of which are so tattered, blurred, and defaced by the ravages of Time, that their characters are hardly decipherable, and the record is differently interpreted by different experts. Moreover, to continue the simile, this chapter is incomplete both at the beginning and at the end, so that we know not how many pages preceded those we possess, or how many succeeding pages have been torn out and destroyed; for the pages of our history are not numbered. We only know that some are wanting, and that there is a gap, unfilled as yet by the history of any other country, between this first dim and ancient record and the better preserved chapters which succeed it.

In more scientific and matter-of-fact language, there are certain parts of the British Isles where the Cambrian rocks to be described in the next chapter rest on a still older series of rocks. Most of these Pre-Cambrian rocks are crystalline and foliated—gneisses and schists; some however are clearly of sedimentary origin—quartzites, conglomerates, and limestones, while others are as distinctly of volcanic origin—lavas, ashes, and agglomerates. All, however, are now everywhere more or less metamorphosed. For these ancient rocks Dana's name of Archæan is now very generally adopted; but as we are only beginning to know something about them, and as the two series are everywhere separated by a marked unconformity, the simple name of Pre-Cambrian is often used

as a convenient designation, until they have been more thoroughly investigated.

With the exception of a very doubtful organism, which has been named *Eozoon*, no fossils have been found in this Pre-Cambrian series, so that it is regarded by some as having been formed at a period anterior to the introduction of life on the globe (the Azoic era). Not only is the evidence of organic remains wanting, but the evidences drawn from their order of superposition are matters of controversy. Some authorities, like Dr. Sterry Hunt and Dr. H. Hicks, hold that the chief Archæan rock-groups, crystalline as well as clastic, have a recognizable sequence in time. Others, like Lehman, Lapworth, Peach, and Horne, hold that the planes of foliation in gneisses and schists "are not planes of deposition, but planes of shearing and cleavage,"[1] and that, as a consequence, the ordinary rules of superposition when applied to foliated rocks afford no certain clue to their relative antiquity. A consequence of this is, that there are no means of correlating the Archæan rocks of one area with those of another, and as Dr. A. Geikie remarks,[2] "it must be conceded that these rocks may have originated at many widely separated periods of early geological time, but that as yet no means have been devised of establishing any generally applicable tests of their relative antiquity."

### *Stratigraphy.*

It is only in a few isolated districts that these Archæan rocks rise up from beneath those which are known to be of Cambrian age, but there are some other localities where metamorphic rocks occur which from their lithological similarity are believed to be also Pre-Cambrian.

The principal areas of Archæan rock in Britain are the following:—Scotland (Hebrides and north-west coast); Wales (Pembroke, Carnarvon, and Anglesey); Shropshire (the Wrekin area); the Malvern Hills; Charnwood Forest; the Lizard peninsula; and county Donegal in Ireland.

[1] Lapworth, "Geol. Mag.," 1885, p. 106.
[2] "Text-Book of Geology," first edition, p. 637.

Some account of these will be given in the above order, commencing with Scotland, because their existence was first established in that country, where they occupy a larger area than in any other part of Britain, and their structure can be studied in the fine cliff sections along the coast.

### 1. Scotland.

The whole of the Outer Hebrides (Lewis, &c.) and the western parts of Sutherland and Ross consist of Archæan rocks. Their age and position was first established by Sir R. Murchison, who described them under the name of "Fundamental or Lewisian Gneiss," pointing out that they had a definite strike from N.N.W. to S.S.E., and that they were overlain unconformably by the fossiliferous Palæozoic rocks.

The general characters of this gneissic group are thus described by Dr. A. Geikie:[1] "They consist of a tough massive gneiss, usually hornblendic, with bands of hornblende schist, actinolite schist, eclogite, mica-schist, sericite-schist, and other crystalline rocks. In two or three places they enclose bands of limestone, but neither in these nor in any other parts of their mass has the least trace of any organic structure been detected. In traversing the western seaboard, from Cape Wrath to Loch Torridon, I have ascertained that these ancient rocks are disposed in several broad anticlinal and synclinal folds, the angles of dip often not exceeding from 30° to 40°, and the strata succeeding each other with unexpected regularity, though here and there showing great local crumpling."

A prominent feature in this Lewisian gneiss, and especially in the lower part of it, is the frequent occurrence of pegmatite in veins which sometimes seem to be interstratified with the gneiss, and sometimes traverse it in different directions. Dr. Geikie appears to regard these granite veins as the result of extreme metamorphism, and not as subsequent intrusion.

By the faults and inversions, which will be mentioned later on (Chapter III.), small strips of Archæan gneiss are

[1] "Text-Book of Geology," first edition, p. 640.

brought in again and again to the eastward; and it is not yet known how much of the gneissic and schistose rocks which compose the Highlands should be regarded as Archæan.

## 2. Wales.

Wherever the base of the Cambrian system is found in Wales it is seen to rest on a floor of Archæan rock, and though this only occurs in two or three isolated districts, yet, if we could strip off the newer rocks, we should doubtless find that this floor everywhere underlies them.

**Pembrokeshire.**—In this county a tract of Archæan rocks extends from Ramsey Sound through St. Davids and Llanhowel for a distance of about eight miles, with a maximum width of two miles. On the maps of the Geological Survey this is coloured partly as igneous rock (Granite, Syenite, Felsite, &c.), and partly as metamorphosed Cambrian. To Dr. H. Hicks belongs the credit of showing that these are really Pre-Cambrian rocks, this age being first claimed for them in 1871, and their stratigraphy being subsequently worked out by Dr. Hicks, who has published his views in a series of papers.[1] His conclusions may be thus summarized: that the base of the Cambrian series is marked by a conglomerate containing pebbles of the underlying rocks; that this conglomerate rests on a series of schists, argillites, and volcanic breccias, under which is another series of quartz-felsites and halleflintas; and below this, again, comes a granitoid rock, which he regards as the basement part of the metamorphic series. To the last, or granitoid group, he gave the name of Dimetian, the middle group he called Arvonian, and the upper one Pebidian. The beds strike from E.N.E. to W.S.W., and their estimated thickness is 18,000 feet (see fig. 1).

Dr. Hicks' views have recently (1883) been called in question by Dr. Geikie, who maintains the correctness of the view taken by the original surveyors, viz., that the so-called Dimetian is an intrusive granite, and that there is no break between the so-called Pebidian and the Cambrian.

[1] "Quart. Journ. Geol. Soc.," vols., xxxi., xxxiii., xxxiv., xxxv.

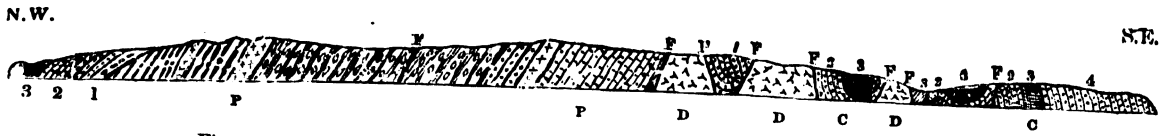



Fig. 1. Section through the Archæan ridge, south-west of St. Davids (by Dr. Hicks).

C = Cambrian. { 3. Shales. 2. Sandstones. 1. Conglomerate.

P = Pebidian.
D = Dimetian.
F = Faults.

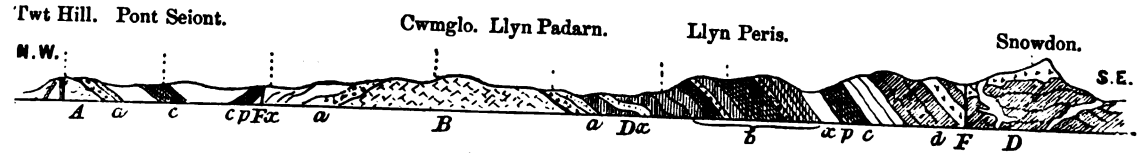



Fig. 2. Diagram Section across Carnarvonshire (by Prof. Hughes).

Ordovician. { *d*. Bala Series. *c*. Arenig Series.

Cambrian. { *b*. Harlech and Lingula Flags. *a*. Basement Beds.

A and B = Archæan ridges.

F = Faults.
D = Dykes.
*x* = Broken ground.

To this attack Dr. Hicks has replied, admitting that some of the evidence he originally adduced to prove the metamorphic origin of the Dimetian is fallacious, but maintaining that his main position is unshaken, that the Cambrian does rest unconformably upon his Pebidian series, and that its basement conglomerate does contain recognizable fragments of the Dimetian and other pre-existent rocks.

Most geologists who have examined the district concur in this view, and regard the rocks as Pre-Cambrian; but whether the Dimetian of Dr. Hicks is intrusive granite or granitoid gneiss, and whether the Arvonian form a series worthy of separation from the Pebidian, are matters upon which there is much difference of opinion. The thickness of the Arvonian and Pebidian is, perhaps, 8,000 feet.

Another tract, mapped as "altered Cambrian" by the Survey, but probably Pre-Cambrian, lies to the east of that above described, and runs inland from St. Bride's Bay, north of Haverfordwest.

**Carnarvonshire.**—In this county there are also two areas of Pre-Cambrian rocks. The first extends from Llanllifin in the south to Bethesda in the north, a distance of about fifteen miles, and has a maximum width of two miles, but narrows toward the north. On the Geological Survey map it is coloured as "intrusive felspathic porphyry," with "altered Cambrian" round its southern border. Dr. Hicks and Professor Bonney have shown that these are Pre-Cambrian rocks, and that they are overlain unconformably by unaltered Cambrian conglomerate; the porphyry is a rhyolitic felsite, and the other beds (breccias and schistose rocks) are comparable to the Pebidian.

A second tract (coloured in the same manner on the Survey map) extends from Carnarvon to Bangor, a distance of about ten miles, with a width of over a mile in the central part. This has been well described by Professor Hughes,[1] who shows that the ridge consists of three rock groups—a granitoid rock at the southern end (Twt Hill), against which unaltered Cambrian conglomerates are resting; a red and purple felsitic series, which extends nearly

[1] "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 137, and vol. xxxv. p. 682.

to Bangor, and is overlain by grits, slates, and agglomerates (the altered Cambrian of the Geological Survey). It is shown, however, that the true Cambrian conglomerate overlies this Bangor volcanic series, and the whole is, therefore, proved to be of Pre-Cambrian age (see figs. 2 and 5).

Professor Bonney observes that the following facts are indisputable:[1]—

1. That the granitoid rock resembles that of St. Davids and the Wrekin.
2. That the felstone is a rhyolitic lava-flow.
3. That the base of the Cambrian is a conglomerate, which contains well-rolled pebbles of the rhyolite.
4. That between this conglomerate and the rhyolite there is a series of argillites and breccias, with numerous fragments of volcanic scoria and of rhyolitic lava, derived probably from the destruction of contemporaneous volcanoes.

**Anglesey.**—A large portion of this island consists of metamorphic rocks, but opinions differ much as to the order of succession which they exhibit. Dr. Hicks finds a similar succession to that in other parts of Wales, namely, (1) a granitoid series, (2) compact halleflintas, (3) quartzose and micaceous schists. Professor Bonney[2] thinks it safer at present to group them in two divisions: (a) a lower series of granitoid gneiss and highly crystalline schists, and (b) an upper series of well-bedded chloritic or micaceous schists, with some quartzites. He also remarks that the greater antiquity of the granitoid series as well as its non-intrusive character is placed beyond doubt by the fact that, near Llanfaelog, both series are in close proximity, and the newer series contains bands of well-rounded pebbles of a rock indistinguishable from the neighbouring granitoid gneiss. This truly metamorphic series is succeeded by a hypo-metamorphic series of slaty and schistose rocks, sometimes of volcanic origin, and probably corresponding to Pebidian.

The undoubted Palæozoic rocks which overlie these slaty

[1] "Brit. Assoc. Rep.," 1884.
[2] Loc. cit.

beds have in many places a conglomeratic base, containing fragments derived from both the Archæan series, but whether this bed is of Cambrian or Ordovician age has not yet been decided, Dr. Hicks and Professor Hughes holding the former view, and Dr. Callaway the latter. The succeeding slates are either Tremadoc or Arenig (see p. 69).

### 3. England.

**The Wrekin District.**—The Wrekin, with the two minor summits, Lawrence and Ercal Hills, forms a ridge about three miles long. On the map of the Geological Survey it is coloured as intrusive Greenstone, and is surrounded by a zone of altered Caradoc (Ordovician).

This region has been studied principally by Mr. Allport,[1] Dr. Callaway, and Professor Bonney,[2] who have shown that the Wrekin is an ancient volcano, and consists of a felstone or devitrified rhyolite, with masses of volcanic agglomerate and ash; while at both ends of the ridge (Ercal and Primrose hills) there is a granitoid rock, which is probably older than the volcanic series, though the lines of contact appear to be faults.

The Wrekin is only the loftiest of a series of isolated hills and ridges, which form a chain about twenty-nine miles in length from the extreme points, Lilleshall Hill on the N.E. to Ragleth Hill, near Caer Caradoc, on the S.W. The rhyolitic lava also appears to the N.W., near the village of Wrockwardine, where parts of it exhibit beautiful perlitic and spherulitic structures.

As regards the quartzite on the flanks of the Wrekin, Dr. Callaway has shown that it contains pebbles of the rhyolite and is overlain by sandstones of the Lingula Flag group; it is therefore either of Lower Cambrian age, or of still earlier date.

**The Malvern Hills.**—The length of this ridge is about seven miles, and its greatest breadth not more than half a mile. The position of the Archæan rocks can be seen in fig. 19; they are flanked on the west by the

[1] "Quart. Journ. Geol. Soc.," vol. xxxiii. p. 449.
[2] Op. cit., vol. xxxv. p. 643, and vol. xxxviii. p. 119.

Hollybush Sandstone of Upper Cambrian age, and on the east by Triassic beds. The north end of the ridge consists of a coarse granitoid gneiss, composed of quartz, orthoclase, and a little hornblende or mica, but toward the south there are finer gneisses interbedded with micaceous schists. These strike roughly from N.W. to S.E., and are inclined at high angles, being often nearly vertical.

**Charnwood Forest.**—This area rises out of the Trias to the south-east of the Leicestershire coalfield, and measures some nine miles from N.W. to S.E., and rather more than four from S.W. to N.E. The older rocks of this district were formerly regarded as Cambrian, but our most recent knowledge of them comes from Professor Bonney and Rev. E. Hill, who regard them as Pre-Cambrian, and describe the following succession in descending order:—

5. Slates of Swithland and Groby.
4. Slates with bands of pebbly quartz grit.
3. Agglomerates and schistose porphyritic rocks.
2. A great series of grits, slates, volcanic ashes, and agglomerates, some of the last being very coarse, and containing large fragments of rhyolitic lava.
1. Slates and fine grits, the latter probably of volcanic origin.

The strike is from N.W. to S.E., the older beds occurring on the northern, and the newer on the southern side. Masses of Syenite and Diorite are intruded among them.

Professor Bonney remarks that "the rocks of the Forest area are probably prolonged underground beneath the Trias and Coal-measures for a considerable distance, since they have been struck once or twice in borings, and a number of bosses of crystalline rock crop out from the Trias in the neighbourhood of Narborough, south of the Forest." With regard to the age of this ancient series, he observes that the materials are largely volcanic, and of the same acidic or rhyolitic type as the lavas of St. Davids and the Wrekin; further, that they differ markedly from the lavas of Ordovician age, and no contemporaneous lavas are yet known among undoubted Cambrian rocks.

**Staffordshire and Warwickshire.**—In Warwickshire, near Nuneaton, a quartzite which was supposed to be altered Carboniferous grit, but which Professor Lapworth has recently proved to be Upper Cambrian, rests on felspathic ashes and quartz-felsites, which probably belong to the Charnwood Series.

At the south end of the Lickey Hills, and beneath the quartzite of that region, Professor Lapworth has recently discovered a series of igneous rocks and sandstones, which are presumably of the same (*i.e.* Charnwood) age.

**Cornwall.**—A large portion of the promontory which terminates in the Lizard Point, consists of metamorphosed stratified rocks, which are regarded as Archæan by Professor Bonney. He distinguishes three groups in the following ascending order:—

1. A Micaceous group, consisting chiefly of compact dull green schists, composed of green mica and light green hornblende.
2. A Hornblendic group, consisting of hornblende-schists, generally dark green, hard and distinctly bedded, often banded in layers of quartzose, felspathic, epidotic and hornblendic constituents.
3. A Granulitic group, consisting of dark grey hornblende-schist and light reddish-grey granulite in alternate bands. These alternations seem to indicate original bedding, and it passes insensibly into the hornblendic group above.

The area occupied by these rocks is bounded on the north by a fault running from coast to coast, so that there is no direct evidence to decide the real age of the series.

### 4. Ireland.

In the north-west of Ireland (co. Donegal), there is a considerable area of metamorphic rock, which is in all probability a continuation of the Scottish Highland tract. The red Cambrian sandstone does not occur, but according to Professor Hull there is a massive granitoid gneiss like that of the Hebrides, overlain unconformably by quartzites,

limestones, and schists of probable Ordovician age. Dr. Callaway, however, in a recent paper,[1] maintains that the granitic rock is intrusive, and not a metamorphosed sedimentary mass, its foliation being the result of intense lateral pressure. The proof of this great pressure is found in the plication of the schists into which the granite is injected, inverted folds and overthrust faults being frequent, as in the north of Scotland.

The metamorphosed sedimentary rocks are grouped by Dr. Callaway into two series, the older being truly crystalline, and consisting of quartzites, quartz-schists, hornblendic and micaceous schists and crystalline limestones. These are succeeded on the east by a semi-crystalline or hypo-metamorphic series of very variable composition—quartzites, grits, limestones, dolomites, phyllites, and micaceous schists. The real age of these two rock-groups is at present quite uncertain, but the older series may be Archæan.

### *Foreign Archæan Rocks.*

**North America.**—The largest and most thoroughly explored area of Archæan rocks is that in Canada, forming a broadly V-shaped tract, extending from Labrador to the borders of Lake Huron, and thence north-westward to the Arctic Ocean. These rocks were first described by Sir W. Logan, under the name of *Laurentian*, and he divided them into two series: (1) a lower group more than 20,000 feet thick, consisting chiefly of granitoid gneiss, and schists with bands of limestone, magnetic iron ore, and quartz-rock; and (2) an upper group, 10,000 feet thick, consisting of gneiss with Labrador felspar, schists, limestones, and magnetic iron ore. He also found in the neighbourhood of Lake Huron a third series, resting unconformably on Laurentian gneiss, which he named the *Huronian* series. This includes a vast thickness (more than 10,000 feet) of conglomerates, slates, limestones, and quartz-rocks.

Dr. Selwyn has recently contended that the Laurentian series is divisible into a gneissic group and a schist and limestone group, the latter being always above the former,

[1] "Quart. Journ. Geol. Soc.," vol. xli. p. 221.

and that the Huronian is the equivalent of the limestone-bearing portion of the Laurentian.

**Life.**—The Laurentian limestones of Canada have yielded the curious structures known as *Eozoon canadense*, and supposed to be the earliest known form of animal life. These masses consist of a mixture of calcite and serpentine disposed in alternate layers, and so arranged as to suggest that they are the remains of an organic structure. Dr. Dawson and Dr. Carpenter believe them to have been formed by an organism of Foraminiferal type, which built up large compound sheets or reefs much in the same way as coral reefs are now formed. These authorities regard the calcite as the framework or skeleton of the mass, and the serpentine as filling the cavities which were originally occupied by the animals. Other observers have, however, disputed these conclusions, and maintain that the so-called Eozoon is merely a mineral aggregation devoid of any organic structure. General opinion seems now to be against the idea of its organic origin.

**Localities in Europe.**—Archæan rocks occupy extensive areas in the north of Europe, more than three-fourths of the Scandinavian peninsula consisting of Archæan gneiss, with masses of schist and quartzite, and then bands of crystalline limestone in the upper part of the series. No definite succession, however, has yet been made out. Rocks believed to be of the same age extend through Finland into Russia, and reappear in the extreme north-east of that country.

In central Europe they appear in several isolated areas surrounded by the stratified rocks of much newer formations. The best known of these areas is that occupying parts of Saxony, Bohemia, and Bavaria between Dresden and the valley of the Danube. The lowest rocks are red gneiss and granite (Bojan gneiss), succeeded by grey gneiss with schistose rocks and beds of limestone and serpentine (Hercynian of Gumbel), and the highest beds consist of mica-schist passing up into clay slate and shales (the Pribram shales), which are overlaid unconformably by the Lowest Cambrian rocks.

Pre-Cambrian rocks are also known to exist in the Carpathian mountains and the Pyrenees; gneissic rocks sup-

posed to be of Archæan age occur in Normandy and Brittany, where they present a front of lofty cliffs to the waves of the Atlantic. There can be little doubt that they extend underneath the newer rocks between these districts, and form the floor upon which the latter rest throughout the whole European area.

### *Origin and Method of Formation.*

It is very doubtful whether the Archæan rocks were originally accumulated as marine sediments, and it has been suggested by Mr. J. E. Marr[1] that they were mainly of terrestrial and volcanic origin. He points out that an abnormal amount of volcanic activity seems to have occurred in Archæan times. The metamorphic rocks are everywhere penetrated by granite, and much of this granite is shown to be of Archæan age by the occurrence of pebbles derived from it in the Cambrian conglomerates, and by the comparative rarity of granitic intrusions in the Cambrian series. Further, as we have seen, the upper part of the Archæan consists mainly of lava flows, tuffs, and agglomerates, while it is quite possible that some of the hornblendic and green schistose rocks of Cornwall and Anglesey may be only metamorphosed tuffs. Even the limestones are lenticular masses of small extent, and might have been deposited in lakes or by calcareous springs in volcanic districts. Finally, the site of at least one Archæan volcano (the Wrekin) is known, and others probably existed near St. Davids, Bangor, and Charnwood Forest.

Mr. Marr also remarks upon the extreme irregularity which the surface of the Archæan rocks presents; they generally rise up as massive ridges from beneath the Cambrian beds, the latter thinning out by overlap against the flanks of these ridges. This arrangement points "to the submergence of great mountain masses sculptured by subaerial denudation, and this would also account for the remarkable character of the boulder conglomerates found in Cambrian beds of different ages, where they rest upon Archæan rocks" (op. cit., p. 226).

[1] "Origin of Archæan Rocks," "Geol. Mag.," Dec. 2, vol. x. p. 263.

From these and other facts he concludes that Archæan time was one of continued and universal vulcanicity, and that the amount of erosion and denudation which took place at its close was so violent, rapid, and extensive that great masses of rock, which had been metamorphosed at a considerable depth below the original Archæan land, were in many places brought to the surface; while the greater part of the unaltered surface rocks were swept away and re-deposited as Cambrian sediment.

Without entirely acquiescing in Mr. Marr's hypothesis, there can be little doubt that a large portion of the British Archæan rocks are volcanic, and that only a small proportion are marine, and that they were accumulated in a volcanic district which was eventually elevated into lofty land. Further, that after remaining as a land surface for a considerable period of time, this land was gradually submerged, and received the Cambrian deposits, sinking till only its topmost peaks remained above the Cambrian waters.

Between this chapter of the geological history of Britain and that which succeeds it there is therefore a gap in the record. This break is no doubt wholly or partially filled elsewhere by a series of deposits, some of which may have been marine; but of these we have at present no certain knowledge, and, when they are discovered, they will doubtless be found to contain the remains of the first beginnings of life on the globe.

## CHAPTER II.

### THE CAMBRIAN SYSTEM.

*The Classification of the Lower Palæozoic Rocks.*

THE nomenclature of the great Lower Palæozoic or Cambro-Silurian series has for many years been in an unsettled state. The well-known name *Silurian* (from the tribe of Silures who inhabited South Wales) was first introduced by Sir Roderick Murchison in 1835, to designate the series of rocks which he had studied in Shropshire and South Wales; and he afterwards divided this into an Upper and Lower Silurian.

Meantime Professor Sedgwick had worked out the complete succession in North Wales, and found that the rocks fell naturally into two great series, to the lower of which he gave the name of *Cambrian*, which he divided into Lower, Middle, and Upper, while for the uppermost series he adopted Murchison's name of Silurian.

Sedgwick worked out the succession from below upwards, and Murchison worked from above downwards; and for a long time neither was aware of the fact that their systems overlapped each other. Murchison supposed that Sedgwick's Cambrian lay entirely below his Silurian; but when the fossils were collected and described, it was found that the Upper Cambrian was equivalent to the Lower Silurian, and this fact led to much subsequent controversy.

As Murchison became the Director-General of the Geological Survey, his nomenclature was naturally adopted by the surveyors, and as they found that his Lower Silurian had no natural base, group after group of Sedgwick's Cambrian was gradually absorbed into it, till the Lower Silurian came to include the whole of the rocks (below the Upper Silurian) in which any fossils had been found; leaving only

a few thousand feet of slate and grit "as a tribute to the genius of the founder of the Cambrian System." This was obviously unfair and unscientific, since the so-called Lower Silurian was in reality a part of Sedgwick's Cambrian series, the delineation of which by Sedgwick was accurate and complete. Still it was done, and the name Lower Silurian was generally adopted both in England and abroad.

There has, however, arisen a school of geologists who feel the injustice of this, and wish to revert to the more logical nomenclature of the Woodwardian professor; but to this course there are two serious objections: (1) It is not likely that the Survey authorities would ever be induced to accept it, and consequently there would always be two British Palæozoic classifications; (2) although Sedgwick's Cambrian is a perfectly complete and continuous series, yet it is palæontologically divisible into two portions, each of which is entitled to the rank of a system. In accordance, therefore, with the principles laid down in Part IV., Chapter III., and in spite of the conformable sequence, we are compelled to recognize two systems in Sedgwick's Cambrian.

The fact is, Sedgwick and Murchison both described more than one system of rocks, and each included two systems under one name. Sedgwick had clearly a right to call one system Cambrian and Murchison to call one Silurian, but there is really a third intermediate system, containing the second great fauna in the life-history of the globe, and to this neither geologist has a distinct claim.

Professor Lapworth has strongly insisted upon these facts, and has proposed the name *Ordovician* (from the tribe of the Ordovices who inhabited North Wales) for the intermediate system, remarking:[1] "That so long as present systems of nomenclature survive, nothing can disturb the application of the title Cambrian to the rocks of the 'Primordial Series,' or that of Silurian to the strata of the 'Third Fauna.' It is vastly different, however, with the intermediate series, which has been the object of incessant disputes from the day it was recognized until now."

[1] "Geol. Mag.," Dec. 2, vol. vi. p. 14.

He thinks it time, therefore, to end these differences by giving this central system the name *Ordovician*, which is equally euphonious, and as strictly significant of the area where its strata are typically developed, as the names employed for the systems above and below.

Sir A. Ramsay has admitted that if he were to recommence the mapping of Wales *de novo*, he would separate the Lower Palæozoic rocks into three divisions.

Mr. Etheridge, too, the late Palæontologist of the Survey, thus sums up the matter in his presidential address to the Geological Society (1881): "The recognition of a tripartite grouping of the faunas and strata between the base of the Old Red Sandstone and the Harlech Series cannot be disputed; each is characteristic, and possesses a broadly marked aspect or facies."

We may hope, therefore, that this classification will ultimately be accepted by the Geological Survey.

The following table shows the different arrangements which the student will find current at the present time, the last or right-hand column being that which will be adopted in this volume.

| | Sedgwick, 1836. | Murchison, 1839-47. | Geological Survey. | Lapworth, 1879. |
|---|---|---|---|---|
| Clunian. Salopian. Valentian. | Silurian. | Upper Silurian. | Upper Silurian. | Silurian. |
| Bala Series. Llandeilo Flags. Arenig Series. | Cambrian. | Lower Silurian. | Lower Silurian. | Ordovician. |
| Tremadoc Slates. Lingula Flags. Menevian. Harlech Series. | | Primordial Silurian. Cambrian. | | Cambrian. |

In this chapter the Cambrian rocks will be described.

### *Areas of Cambrian Rocks.*

Cambrian rocks rise to the surface in several parts of the British Islands, but they nowhere occupy any very large tract of country, so that we can only compare their isolated

exposures, and cannot trace their stratigraphical variations continuously from one district to another.

In England and Wales there are five districts where the occurrence of Cambrian strata is unquestionable—South Wales, North Wales, Shropshire, Warwickshire, and the Malverns; their existence in the Lake District is doubtful. In Scotland they have only yet been found in the far north. In Ireland there are three areas, Wicklow, Wexford, and Galway.

In England, the Lower Cambrian tracts are probably continuous beneath the Welsh Ordovician. The Upper Cambrian extend eastward beyond the lower beds, and doubtless underlie all newer rocks in the eastern counties.

Wherever the basement beds of this system are exposed, they are seen to rest unconformably on an uneven surface of Archæan rock.

The system admits of subdivision as follows:—

| | |
|---|---|
| Upper . | Tremadoc Slates.<br>Lingula Flags (in three stages). |
| Lower . | Menevian Series.<br>Harlech Series (in two stages). |

### *Life of the Period.*

Great interest attaches to the fossils which have been found in Cambrian rocks, because they include the remains of the oldest animals hitherto discovered. The earliest known fauna is that of the Harlech and Longmynd rocks, and our present knowledge of it is chiefly obtained from one locality, viz., the Harlech rocks of Pembrokeshire, in which Dr. Hicks has found no less than thirty-two species referable to eighteen genera and four different classes of life. The four classes here represented are Spongida, Crustacea, Brachiopoda, and Pteropoda. The Longmynd and Irish Cambrians yield representatives of two other groups, the Annelida and the Hydrozoa (if *Oldhamia* is rightly referred to the latter).

Now, although all these classes are comparatively low in

the scale of life, yet they are widely different from one another, and we cannot suppose them to be the remains of the first creatures that peopled the earth. At the same time, it may be noted that many of the genera are comprehensive types, *i.e.*, types which combine characters now belonging to several separate genera or orders, while others are persistent types, whose organization was such as to enable them to resist all changes, and to survive until the present day.

Thus, the Trilobites and Ostracoda are generalized or synthetic types, from which several other orders of Crustacea may well have been derived by differentiation. Of the Brachiopoda, *Lingula* and *Discina* are similar synthetic types exhibiting some Annelidian characters; they are, at the same time, persistent forms; *Orthis* is more specialized. The Pteropoda are persistent representatives of the embryonic forms of Gasteropoda, and were therefore likely to precede the latter class. The Hexactinellid Sponges are at once a lowly and a persistent group.

But although each group is represented by forms which have a pristine facies, yet it is evident that none are likely to have originated where they are now found, and that they must have had ancestors; these ancestors will no doubt be discovered some day in rocks of an age intermediate between the Archæan and the Cambrian; though such rocks may perhaps never be found in the British Islands.

Representatives of other classes make their appearance in the beds above the Harlech series; thus the first known Cystidean Echinoderm occurs in the Menevian, and the first Crinoid in the Tremadoc (*Dendrocrinus*). Phyllopod Crustaceans make their first appearance in the Lingula Flags, and Lamellibranch Mollusca are first known in the Tremadoc. All these are among the less highly organized forms of the groups to which they belong, but it is surprising to find the two highest classes of the Mollusca suddenly making their appearance in Cambrian times, the Heteropoda in the Lingula Flags, and the Cephalopoda in the Tremadoc. Their introduction can only be accounted for on the supposition that they had been developed elsewhere, and had thence migrated into the European area.

The probable locality whence they came will be indicated in the section on Physical Geography (see p. 78).

The following are the principal and characteristic fossils of the several divisions of the Cambrian System :—

### Harlech Fossils.

*Spongida.*—Protospongia diffusa, P. fenestrata, P. major.

*Hydrozoa* (?).—Oldhamia (the markings so called may be the galleries of minute Crustacea).

*Annelida.*—Arenicolites sparsus and A. uriconiensis.

*Crustacea.*—Conocoryphe Lyellii, C. solvensis, Microdiscus sculptus, Paradoxides aurora, P. Harknessi, P. solvensis, Plutonia Sedgwickii.

*Brachiopoda.*—Discina pileolus, Lingulella primæva, and L. ferruginea, Orthis sagittalis (ranges to Tremadoc).

*Pteropoda.*—Theca antiqua, Th. penultima.

### Menevian Fossils.

*Spongida.*—Protospongia, all the Harlech species, and P. flabellata.

*Echinodermata.*—Protocystites menevensis.

*Annelida.*—Arenicolites didymus and A. sparsus.

*Crustacea.*—Anopolenus Henrici, Arionellus longicephalus, Conocoryphe applanata, Erinnys venulosa, Paradoxides Davidis.

*Brachiopoda.*—The Harlech species and Orthis Hicksii.

*Pteropoda.*—Cyrtotheca hamula, Stenotheca cornucopia, Theca corrugata (ranges to Tremadoc).

### Lingula Flag Fossils.

*Hydrozoa* (?).—Dictyonema sociale (upper beds only).

*Annelida.*—Cruziana semiplicata (foot-tracks).

*Crustacea.*—Agnostus pisiformis (princeps), Ag. nodosus, Conocoryphe depressa, C. invita, Microdiscus punctatus, Olenus micrurus, Hymenocaris vermicauda.

*Brachiopoda.*—Lingulella Davisii, Obelella Salteri, Kutorgina cingulata, Orthis lenticularis.

*Heteropoda.*—Bellerophon cambrensis.

*Pteropoda*.—Theca corrugata and Th. obtusa (lower beds only).

TREMADOC FOSSILS.

*Hydrozoa*.—Bryograptus Callavei, Dictyonema sociale (lower beds only).

*Echinodermata*.—Dendrocrinus cambrensis, Palæasterina ramseyensis.

*Crustacea*.—Angelina Sedgwickii, Neseuretus ramseyensis, Niobe Homfrayi, N. menapiensis, Ogygia scutatrix, Asaphus Homfrayi, Psilocephalus innotatus.

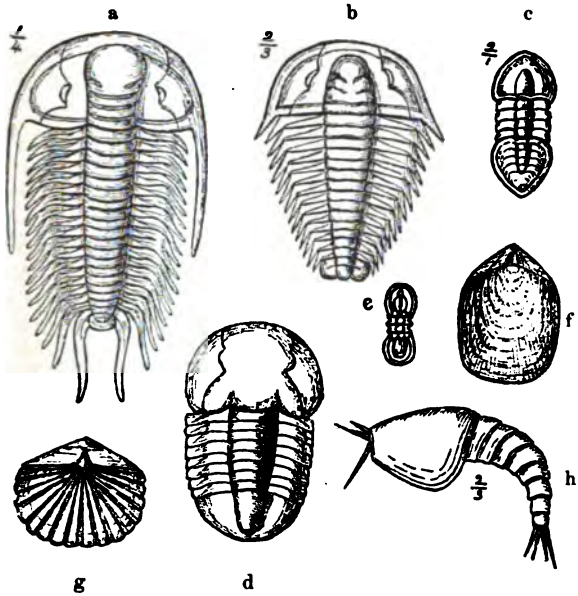



Fig. 3. Group of Cambrian Fossils.[1]

a. Paradoxides Davidis.
b. Olenus micrurus.
c. Microdiscus sculptus.
d. Psilocephalus innotatus.
e. Agnostus princeps.
f. Lingula Davisii.
g. Orthis Carausii.
h. Hymenocaris vermicauda.

[1] Fractional numbers appended to the figures in these groups indicate the proportion they bear to the size of the originals; the figures without these indices are of the natural size.

*Brachiopoda.*—Lingulella lepis, Obolella Beltii, Orthis Carausii.

*Lamellibranchiata.* — Glyptarca primæva, Ctenodonta menapiensis, Modiopsis ramseyensis.

*Pteropoda.*—Theca ovata, Th. cuspidata.

*Heteropoda.*—Bellerophon ramseyensis, B. solvensis.

*Cephalopoda.*—Cyrtoceras precox, Orthoceras sericeum (upper beds).

## *Stratigraphy.*

### 1. South Wales.

Cambrian strata form the greater part of North Pembrokeshire, and surround the two areas of Pre-Cambrian rocks. Our detailed knowledge of this district is chiefly due to the researches of Dr. Hicks, from whose papers the following account is mainly taken:[1]—

**Harlech Series.**—The basal bed of this series is the Cambrian conglomerate so frequently mentioned in the preceding chapter. Near St. Davids it is about sixty feet thick, and consists of well-rolled pebbles and boulders set in a matrix which is a mixture of arkose and ashy materials; sometimes the ashy element appears to predominate, sometimes it is a true arkose, consisting of quartz-sand, and decomposed felspar. The pebbles vary in size and range up to a foot in diameter; they comprise quartz, quartzite, quartz-felsite, porcellanite, schists, and granitoid rock, all derived from the underlying Archæan rocks.

Over the conglomerate come greenish, flaggy sandstones, and then some red shales and slates with fossils; these are succeeded by a great series of purple sandstones, surmounted by another series of green and purple flags and grits. The grouping proposed by Dr. Hicks for this district is as follows:—

[1] Especially from that in "Pop. Sci. Rev.," New Ser., vol. v. I have also availed myself of Mr. Marr's excellent summary of the Cambrian and Silurian Rocks ("Sedgwick Essay," 1882).

| | | Feet. |
|---|---|---|
| Solva Group. | Grey rocks, with *Paradoxides aurora* | 150 |
| | Red purple and grey grits and slates, with *Paradoxides solvensis* | 1,500 |
| | Yellowish grits and flags, with *P. Harknessi* | 150 |
| Caerfai Group. | Purple sandstones, with Annelids | 1,000 |
| | Red shales, with *Lingulella primæva*, &c. | 50 |
| | Greenish sandstones and conglomerates | 520 |
| | | 3,370 |

If these two groups can be recognized elsewhere, they will rank as divisions of equal value with the Menevian.

**Menevian Series.**—The Solva beds pass gradually into a series of dark flags and shales, which contain a remarkable fauna; above these sandstones again appear, marking, possibly, an upheaval of the area, and certainly indicating some physical change, for with them the species and genera characteristic of the Lower Cambrian die out and disappear. The group is thus subdivided by Dr. Hicks:—

| | Feet. |
|---|---|
| Upper.—Sandstones and shales, with *Orthis Hicksii*. | 100 |
| Middle.—Flags and shales, with *Paradoxides Davidis* | 350 |
| Lower.—Flags and shales, with *Paradoxides Hicksii* | 300 |
| | 750 |

**Lingula Flag Series.**—Much confusion exists with regard to the subdivisions of the Lingula Flags, on account of the following circumstances. As originally described by Professor Sedgwick, it included both the Menevian and Tremadoc, and he divided the whole into Upper, Middle, and Lower groups; the uppermost he subsequently separated as the Tremadoc, giving the name of "Ffestiniog group" to the remainder of his Lingula Flags. In 1865, Sedgwick's "Lower Ffestiniog" was re-named as the Menevian by Salter and Hicks; but there still remained some 5,000 feet in North Wales, for which the name of Lingula Flags was retained. In 1867 this central series was studied by Mr. Belt, and by him divided into three

distinct groups (see below); it is, therefore, important to note that the Lower, Middle, and Upper Lingula Flags of the present terminology are only subdivisions of Sedgwick's "Middle Lingula Flags." This is shown in following tabular view:—

| | Sedgwick, 1836. | Sedgwick, 1847. | Belt, 1867. | |
|---|---|---|---|---|
| Lingula Flags. | Upper = | Tremadoc = | Tremadoc. | |
| | Middle = | Ffestiniog = | 3. Dolgelly.<br>2. Ffestniog.<br>1. Maentwrog. | Lingula Flags. |
| | Lower = | | = Menevian. | |

In the St. Davids area all three divisions of the series are found, and they form a set of sandstones and shales about 2,000 feet thick, occasionally ripple-marked, very barren of fossils, and showing a return of shore conditions. They are thus grouped by Dr. Hicks:—

Upper or Dolgelly = grey shales, with *L. Davisii.*
Middle or Ffestiniog = grey micaceous flags.
Lower or Maentwrog = slates and flags, with *Oleni.*

**Tremadoc Series.**—At Ramsey Island and at Whitesand Bay, in Pembrokeshire, this series is clearly intercalated between the Lingula Flags and the Arenigs. It is about 1,000 feet thick, and is divided into a lower group (200 feet) of dark flaggy sandstones, with *Neseuretus* and *Niobe*, and an upper group (800 feet) of iron-stained flags and slates, with *Asaphus Homfrayi* and *Angelina Sedgwickii.*

## 2. North Wales.

The Cambrian rocks in Carnarvon and Merioneth are brought to the surface by two anticlinal folds, which are separated by the great synclinal of the Snowdon range (see fig. 4). In Carnarvon, the Lower Cambrians flank both sides of the major Archæan ridge, but the Upper Cambrians occur only on the eastern side. In Merioneth, the Upper Cambrians encircle a broad mountain tract, which consists of the Harlech Grits, and stretches inland from the coast, between Harlech and Barmouth.

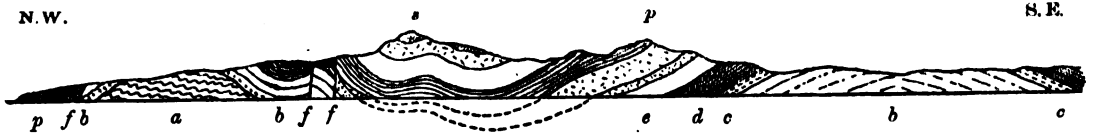



Fig. 4. Diagram section from Menai Strait through Snowdon and the Harlech anticlinal.

Distance about 30 miles.

*s.* Bala Beds of Snowdon.
*p.* Arenig and Llandeilo Beds.
*e.* Tremadoc Slates.
*d.* Lingula Flags.
*c.* Menevian Beds.
*b.* Harlech Beds.
*a.* Pre-Cambrian.
*f.* Faults.

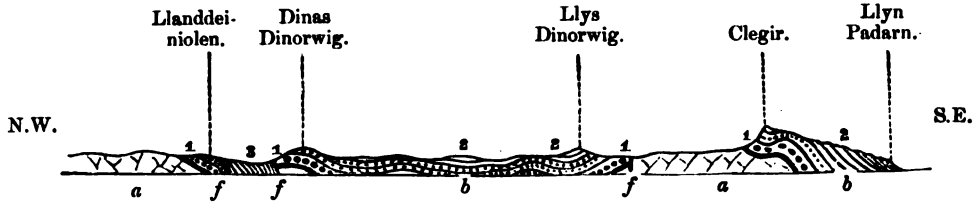



Fig. 5. Section from Llanddeiniolen to Llyn Padarn. (Dr. Hicks, Q. J. G. S., vol. xl., p. 198.)

Distance about 4¼ miles.

3. Black shales (Arenig).
2. Sandstones and grits.
1. Conglomerate.
*b.* Cambrian.
*a.* Pre-Cambrian.
*f.* Faults.

**Harlech Series.**—In Merioneth these rocks are described by Sir A. Ramsay as chiefly coarse quartzose greenish grey grits, formed from the direct waste of granite rocks. Sometimes they are purple and fine-grained, and are interstratified with bands of green and purple slate, especially in the lower part of the series. The visible thickness is estimated at 8,000 feet, but the base is not seen.

In Carnarvon the basement beds of this series are conglomerates and grits, which rest on the Archæan rocks. They contain pebbles of the Dimetian granite, as well as quartz-felsites and porcellanites from the Pebidian series. They are succeeded by a thick series of slates, red, green, purple, and blue, some of which are worked at the celebrated quarries of Penrhyn and Llanberis. "The highest beds," says Sir A. Ramsay,[1] "consist of about 1,300 feet of green, greenish grey, and occasionally purple hard grits, generally thick-bedded and formed of grains of quartz, often but little waterworn, intermingled with felspar grains in smaller proportion." The total thickness is between 6,000 and 7,000 feet. Dr. Hicks considers both his Solva and Caerfai groups to be represented in this series.

All these slates and grits, however, thin rapidly to the north-west, disappearing altogether near Dinorwig and Doldeilo, the basal conglomerate only remaining at Llanddeiniolen, and even this may there be of Arenig age (see fig. 5, which is borrowed from Dr. Hicks' paper).

Professor Hughes[2] has traced similar conglomerate and grit along the eastern flank of this Pre-Cambrian ridge all the way from Twt Hill, Carnarvon, to Garth Point, near Bangor. The nature of the pebbles varies according to the rocks on which the conglomerate rests. Near Carnarvon they are chiefly quartz, near Llanddeiniolen they are all felsite, and near Bangor they are of felsite embedded in a matrix of ashy grit.

**Menevian Series.**—These beds have been found in Merioneth, but are not more than 200 feet thick. They consist of dark blue slates, and may be seen half a mile east of Barmouth, passing conformably into the Lingula

[1] "Geology of North Wales," Mem. Geol. Survey.

[2] "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 137, and vol. xxxv. p. 682.

Flags, from which, however, they are distinguished by their fossil contents. Near Ffestiniog they have the same thickness, but they have not yet been found at Llanberis.

**Lingula Flags.**—This series attains a great thickness in Merioneth. They are well exposed at Dolgelly and Ffestiniog, and are classified as follows by Mr. Belt:—

| | | Feet. |
|---|---|---|
| Upper or Dolgelly. | Soft black slates, with *Olenus scarabæoides* | 300 |
| | Hard blue slates, with *Olenus spinulosus* | 300 |
| Middle or Ffestiniog | Bluish grey flags, with *Olenus micrurus* | 50 |
| | Grey micaceous flags, with *Hymenocaris vermicauda* | 2,000 |
| Lower or Maentwrog. | Black slates and flags, with *Olenus gibbosus* | 1,800 |
| | Sandstones and slaty beds, with *Olenus cataractes* | 700 |
| | | 5,150 |

In Carnarvonshire the Lingula flags thin out rapidly toward the Pre-Cambrian axis; near Llanberis their thickness is only 2,300 feet, and near Bangor they are altogether absent; neither do they occur in Anglesey. The most northerly point to which the group has been traced is Maes-y-Gaer, near Aber, where they rest on grits which are supposed to belong to the Harlech Series. West of this there is only a conglomerate between the Arenig and the Pre-Cambrian rocks.

**Tremadoc Series.**—At Tremadoc and throughout Merioneth, these beds are about 2,000 feet thick, and are similar to those of South Wales, but more fossiliferous. They must, however, thin rapidly to the north-west, for they do not appear to exist in the Llanberis district, and are certainly absent in the Bangor and Carnarvon area, where the conglomerate at the base of the Arenig slates rests against the old Pre-Cambrian ridge, see fig. 2.

At Triorwerth, in Anglesey, Dr. Callaway[1] found *Orthis Carausii* and some obscure Trilobites (Niobe, Neseuretus, Asaphus?) in grits overlying the basal conglomerates of that island, but it is uncertain whether they are Tremadoc or Arenig species.

[1] "Quart. Journ. Geol. Soc.," vol. xxxvi. p. 237, and vol. xl. p. 579.

### 3. SHROPSHIRE.

The Cambrian rocks, which plunge beneath the Ordovician in Merioneth, and lie deep below the Silurians of Montgomery, rise again to the surface in Shropshire, and form the tract known as the Longmynd Hills. Between the ridge called the Stiper Stones and the town of Church Stretton, the Cambrian tract has a width of nine or ten miles; its western border stretches north-east nearly as far as Shrewsbury, and its eastern flank is bordered by the Archæan ridges, which extend as far as the Wrekin. From these ridges (Caer Caradoc, &c.), narrow strips of Cambrian rock are thrown off, which plunge beneath the Ordovician rocks of Hoar Edge.

Fig. 6. Generalized Section through the Longmynd Hills.

E. Caradoc Sandstone.
D. Arenig Beds.
$C^3$. Shineton Shales.
$C^2$. Hollybush Sandstone.
$C^1$. Quartzite.
B B. Longmynd Series.
$A^2$. Chief Archæan axis.
$A^1$. Western Archæan axis.
*f*. Faults.

The section, fig. 6, illustrates the structure of this district, and has been drawn from a sketch kindly furnished by Dr. Callaway, to whom we are chiefly indebted for our knowledge of the rocks it contains.

**Lower Cambrian Series.**—The whole of the Longmynd area, lying between the two Archæan axes, consists of hard red sandstones and conglomerates, grey grits and purple slates, which are supposed to be the equivalents of the Harlech group. Neither top nor base is seen, and yet the sections of the Geological Survey (sheets 34 and 36), show an apparent thickness of 23,000 and 28,000 feet. It is possible, however, that the surveyors were deceived by the prevalent dip to the north-west, and that the beds are

really repeated by a series of isoclinal folds along the eastern flank.[1] Further, Dr. Callaway is of opinion that on the western flank there is a wide synclinal flexure, and that the conglomerate of the central ridge reappears near the western margin. If these surmises are correct, the estimated thickness is much too great, and the amount is probably within 10,000 feet. The boundaries on each side appear to be faults.

**Upper Cambrian Series.**—The Caradoc Archæan is flanked on its south-east side by a quartzite of doubtful age, containing pebbles derived from the Archæan mass.

This is succeeded by greenish micaceous sandstones, which are identified with the Hollybush sandstone of Malvern and Middle Lingula Flags of Wales. They contain *Kutorgina cingulata* in abundance. Outside these are dark blue micaceous shales, termed the Shineton shales by Dr. Callaway, which contain a fauna of Tremadoc affinities. Commencing on the south side of the Wrekin, these shales stretch to the south-west between Dryton and Shineton, as far as Evenwood. Most of the species described by Dr. Callaway (Q.J.G.S., vol. xxxiii. p. 652) are new, but the occurrence of *Dictyonema sociale*, *Asaphus Homfrayi*, with species of *Olenus* and *Conocoryphe* are sufficient to determine the age of the beds.

It is remarkable that in the Longmynd area there should be such a thickness of Lower Cambrian rocks between the two Archæan axes, while no trace of them has been found outside these axes. On the north-west side the junctions are faults, and these lower beds might be concealed, but on the eastern side we have Upper Cambrian resting directly on the Archæan without the intervention of the Longmynd rocks. It would thus appear that there is a break between the Lower and Upper Cambrian of Shropshire, and that during the deposition of the Menevian and Lower Lingula Flags in North Wales, the block composed of Longmynd and Archæan rocks was elevated above the sea and formed a promontory or island, which was only again submerged at the close of the Lingula Flag period, when the Hollybush Sandstone was deposited against its sinking shores.

[1] These are inserted in the section on my own responsibility, and merely as diagrammatic suggestions.

In this supposition of a break between the two groups, Dr. Callaway informs me that he is disposed to concur; but the district requires further investigation. The Bohemian succession presents an analogous case (see p. 77).

### 4. Warwickshire.

**Nuneaton District.**—Messrs. Lapworth and Harrison have recently discovered Upper Cambrian rocks on the eastern side of the Warwickshire Coalfield, where they occupy a tract some ten or twelve miles long by two in width, and had previously been mistaken for altered Carboniferous rocks.

They fall into two main divisions.

| | Feet. |
|---|---|
| Stockingford shales, red, grey, and black . | 2,000 |
| Hartshill quartzite . . . . . | 1,000 |

"The lowest zone of the quartzite is a coarse breccia made up of fragments of red and green felspathic rocks, slaty shales, and various quartz porphyries. These have apparently been derived from an older series of igneous and altered strata, a few beds of which may be seen rising out from below the basal quartzites in the slopes near Caldecott House, Nuneaton.

"The upper beds of the quartzite pass up by gradual intercalations of argillaceous matter into the basement zone of the Stockingford Shales. This consists of purple sandstones and shales, crowded with examples of small Brachiopoda of the genera *Lingulella* and *Obolella*. The higher divisions of the Stockingford Shales are grey and black shales containing *Agnostus pisiformis* and *Beyrichia Angelini*; these beds are faulted down in a long curved strike-fault against the coal-bearing beds of the Upper Carboniferous."[1]

### 5. The Malvern Hills.

In this district Cambrian rocks rest against the western flank of the Archæan axis, but there is nothing to represent

[1] Lapworth, "Proc. Birm. Phil. Soc.," vol. iii. p. 237.

the thick series of the Longmynd area, equivalents of the Upper Cambrian only being found, and these correspond generally with the Shropshire type. Dr. Holl was the first to identify the Malvern Cambrians.

**Hollybush Sandstones.**—These beds are coarse greenish sandstones, conglomeratic where they rest upon the Archæan gneiss, and evidently derived from its detrition. They are doubtless shore deposits of Lingula Flag age, and if they could be followed westward they would probably be found to thicken considerably; but as exposed they form only a narrow strip, and their observed thickness is not more than 600 feet. The principal fossil is *Kutorgina cingulata*.

**Malvern Shales.**—These succeed the sandstones, and consist of black and grey shales, with a total thickness of about 1,000 feet. Their lower and darker portions are probably equivalent to the Upper Lingula Flags or Dolgelly group, for they contain *Olenus spinulosus*, *O. bisulcatus*, and *Agnostus princeps*; but the upper 500 feet of paler shale, as seen in the valley of the White-leaved Oak, may be of Lower Tremadoc age. These upper shales are certainly the same as the Shineton shale of Shropshire, for they contain *Dictyonema sociale* and two of the Shineton Trilobites, *Asaphus Croftii* and *Conophrys salopiensis*.

## 6. The Lake District.

No base has been found to the fossiliferous rocks of this district, but the lowest beds occur in Cumberland, and are dark grey slates and flags, which were first described by Professor Sedgwick, and by him named the Skiddaw Slates.

This series has a thickness of about 10,000 feet, and the fossils of the central and upper portions are certainly Arenig and Llandeilo forms. Mr. J. C. Ward, however, thought that the base of the Arenig series was to be found in a certain bed of grit, and that the lowest part of the Skiddaw Slates was consequently of Upper Cambrian age. This portion he subdivided as follows:—

3. Dark Slates.
2. Sandstone Series of Grassmoor and Whiteside.
1. Dark Slates of Kirk Stile.

He believed that the lowest beds represented the Lingula Flags, but no fossils have yet been found in them. The dark slates (No. 3) have yielded *Niobe Doveri* and *Cybele ovata*, but these do not occur in Wales.

### 7. Ireland.

In the south-east of Ireland, and therefore opposite the coasts of Wales, rocks of Lower Cambrian age are found, and are overlain unconformably by Ordovician rocks, the Upper Cambrian being absent. In Galway, on the other hand, the rocks are supposed to belong to the upper division.

**Wicklow.**—A good section is presented by the cliffs at Bray Head (13 miles south-east of Dublin). Here, at the northern end, are red, purple, and green slates and grits, succeeded on the south by alternating grits and shales. The beds are bent in numerous sharp folds, so that the real thickness is much less than appears at first sight. Jukes and Du Noyer estimated the exposed succession at between 3,000 and 4,000 feet; but the base is not shown, neither is the top actually visible. No fossils have been found in these rocks, except Annelid tracks and the curious bodies known as *Oldhamia*, but on general grounds they are correlated with the Harlech Series.

**Wexford.**—In this county there is a still larger area of Cambrian. Slates and grits similar to those of Wicklow, and containing *Oldhamia*, occupy nearly all the coast-line from Cahore Point to Fethard, and the apparent thickness is estimated at 12,000 feet, though faults are frequent.

**Galway.**—In Connemara there is a thick series of partially metamorphosed rocks underlying beds with Llandeilo fossils, and therefore probably of Upper Cambrian date. They are exposed along the axis of a great anticlinal flexure, which strikes E.S.E. from Clifden to Oughterard, and they consist mainly of quartzites and micaceous slates,

with several bands of marble, including that known as Connemara marble. The thickness is given by Kinahan as 8,000 feet. A section through this district is given by Sir R. Murchison in his "Siluria" (4th edition, p. 180), but the beds in question are there referred to the Ordovician (Lower Silurian).

### 8. North Scotland.

**Torridon Sandstone.**—Resting unconformably upon the Archæan gneiss in the north-west of Scotland lies the thick group of reddish-brown conglomerates and sandstones for which the above name is a convenient designation. As no fossils have yet been found in it, and as it is succeeded unconformably by rocks containing Ordovician fossils, the precise age of the Torridon Sandstone is uncertain, but it is usually regarded as Cambrian, an assumption which finds some confirmation in the Swedish succession (see p. 76).

At its base there are sometimes breccias containing large angular blocks of Archæan gneiss, and Dr. Geikie observes that at such localities the Archæan surface is moulded into rounded dome-like bosses, which forcibly recall the *roches moutonnées* of modern glaciated countries, and suggest the existence of glaciers at this early period of the earth's history. In the western districts the coarse red sandstones which form the mass of the formation lie in nearly horizontal beds, and form exceedingly picturesque scenery, rising into bold escarpments and isolated pyramidal masses, as, for instance, at Applecross; but more to the eastward they are affected by the great disturbances and overthrusts which appear to have resulted in the metamorphism of the Highland rocks. Indurated portions of the Torridon sandstone are thrust upwards and westwards with the Archæan, so that both overlie the Ordovician (see fig. 14), and as they are traced eastward they present evidence of intense pressure and shearing force, assuming a foliated structure with a development of mica along the divisional planes, and finally passing into frilled micaceous schist. The stratigraphy of this district has only recently been worked out,

partly by the labours of Professor Lapworth and other geologists, and partly by Messrs. Peach and Horne, of the Geological Survey.

*Foreign Equivalents.*

EUROPE.

**Scandinavia.**—Here it is interesting to note that, while in Norway, Scania, and Westrogothia, there is a marine sequence representing both Lower and Upper Cambrian, in Dalecarlia (Sweden) there is only a red unfossiliferous sandstone like that of North Scotland, succeeded unconformably by conglomerates and a limestone with fossils of Ordovician type. The normal marine series of Scandinavia is :—

| | |
|---|---|
| Ceratopyge Limestone and Dictyonema Schists | = Tremadoc. |
| Olenus Schists | = Lingula Flags. |
| Paradoxides Schists | = Menevian. |
| Fucoid and Eophyton Sandstones | = Harlech Series. |

**Belgium and North France.**—Cambrian rocks occur in the centre of the Ardennes, and are divided by Dumont into three groups as below :—

3. Salmien : quartz schists, with *Lingula* and *Paradoxides.*
2. Révinnien : dark slates and quartzites, *Dictyonema sociale.*
1. Devillien : greenish quartzites and pale slates, *Oldhamia radiata.*

**Bohemia.**—The name of Barrande is as inseparably connected with the lower Palæozoic rocks of Bohemia as the names of Sedgwick and Murchison are with the same rocks in Britain. Barrande established the Bohemian sequence on a firm palæontological basis, and adopted the nomenclature of Murchison, but recognized a group inferior to the Lower Silurian, calling it the Primordial Silurian, and marking it as Stage C in his local succession. The fossils of this stage are like those of our Menevian,

and some of them are specifically identical with those of the Paradoxides beds of Scandinavia.

The Bohemian stages comparable to our Cambrian are:—

| | | |
|---|---|---|
| Stage D. | *d.* 1. *β.*: pisolitic ironstones | = Tremadoc. |
| | *d.* 1. *α.*: conglomerates and grits | = Lingula Flags. |
| Stage C. | Grey and black shales | = Menevian. |
| Stage B. | Conglomerates, grits and shales | = Harlech. |

The two lower stages only occupy a small area, deposited in a hollow or valley between slopes of Archæan rock. Stage D rests unconformably upon C, and overlaps it on to the Pre-Cambrian rock just as the Hollybush Sandstone comes to rest against the Archæan of Shropshire and the Malverns.

### America.

In spite of the excellent work done by many American geologists, the true sequence of their oldest fossiliferous rocks still remains to be determined. The equivalents of Sedgwick's Lower and Middle Cambrian were clearly included in the Taconic System of Dr. Emmons. This system he founded in 1842, and defined in 1859 as consisting of a Lower and Upper series, the latter containing a "Primordial," or "Sub-Silurian," fauna. His views, however, were not adopted by the officers of the Geological Survey of Canada, who ignored the Taconic System, absorbing its upper portion into the Silurian, and giving a new name (Huronian) to the lower division.

M. Marcou has recently published an elaborate defence of the Taconic System,[1] and has succeeded in showing there is an extensive series of rocks in eastern America belonging to the Upper Taconic of Emmons, and that it contains three different fossil assemblages, which he terms Infra-primordial, Primordial, and Supra-primordial faunæ. The lowest beds are thickest and most fossiliferous in Newfoundland and New Brunswick, and are as follows:—

[1] "Proc. Am. Acad. of Arts and Sc.," New Series, 1885, vol. xii. p. 174.

| | |
|---|---|
| 4. Slates, with *Olenellus*, at Belle Isle Straits | = Lingula Flags. |
| 3. Acadian Group, with *Paradoxides*, 3,000 ft. | = Menevian. |
| 2. Eophyton Sandstone, with *Lingulella spissa*, *Cruziana similis*, and *Eophyton*, 1,500 ft. | = Harlech. |
| 1. Arenicolite slates, with *Aspidella*, 1,000 ft. | |

All these groups, however, thin out to the westward, and the beds which rest upon the Archæan rocks of eastern Canada are sandstones, with *Kutorgina cingulata* (Potsdam sandstone), and homotaxial with our Hollybush sandstone. They are about 500 feet thick, and are succeeded by the Levis limestone, containing *Dikelocephalus* (= Tremadoc). In western Canada and New York the same Potsdam sandstone is succeeded by a calcareous sandstone, which is probably the equivalent of the Levis beds, but contains few Trilobites.

### *Physical Geography.*

The tracts of Cambrian rock which are now exposed to view are so small and isolated, and we know so little of their subterranean extension, that it would be rash to attempt more than a very general sketch of the arrangement of land and water during the period.

In the first place, we may notice that there appear to be three distinct types of Cambrian: (1), the Scotch, or Caledonian type; (2), the Irish, or Hibernian; (3), that of Wales and England, which may be termed the Cambro-Mercian type.

Professor Hull has dwelt upon the differences between the Caledonian and the more southern types, supporting Ramsay's suggestion that the former was deposited in a lake-basin, and concluding that land (formed of Archæan rocks) existed over the greater part of Scotland and North Ireland, with a coast-line trending from N.E. to S.W. He believes that continental land occupied the area of the North Atlantic, and that an open (though. probably,

shallow) sea lay to the east and south-east of that continent. The land, he says, was "probably disposed in ridges and hollows, trending in directions parallel to that of the Outer Hebrides and of the Archæan ridge which I have described as traversing the British Islands. Between these ridges lakes or arms of the sea may have been interposed." [1]

As to the position of the ridges in the English area, such evidence as we possess favours the general disposition indicated by Professor Hull. The Cambrian rocks appear to attain their fullest development in Wales and Shropshire; thence they thin out rapidly to the north-west, and all but the Tremadoc are absent in Anglesey; each division appears to overlap the beds below, but the conglomerate forms a persistent base (see fig. 2). Consequently, we may assume that the beds thin out against an Archæan ridge; and Dr. Callaway remarks that if we prolong the strike of the Bangor and Anglesey ridge, it points southwestward to the Carnsore district (Wexford county), where metamorphic rocks occur which may be Archæan.[2] However this may be, it is pretty clear that a ridge of such rock ran obliquely across what is now the Irish Channel, separating (partially, at any rate) the Irish and Welsh areas of deposition, and remaining above water until the Tremadoc period. This being so, the Irish Cambrians were doubtless deposited in a gulf or sea-space between this ridge and the main coast-line running through the north of Ireland, but whether the ridge was an island, or was a promontory united to the mainland, we cannot at present say.

The structure of the Malvern Hills suggests that the Archæan rocks formed an island there up to the middle of the Cambrian period, and it is clear that the older rocks then extended much farther eastward and northward. In the Longmynd area there is evidence of upheaval before the Hollybush sandstone was formed, but we are at present quite ignorant how far the Lower Cambrian rocks (Harlech and Menevian) extended to the eastward. The evidence,

[1] "Contribs. to the Phys. Hist. of the British Isles," 1882, p. 61.
[2] "Quart. Journ. Geol. Soc.," vol. xl. p. 582.

however, of the Shropshire, Malvern, Lickey, and Nuneaton sections, taken together, suggests that if this lower series was deposited, it was subsequently destroyed by elevation and erosion, so that the whole region formed a land surface at some time previous to the deposition of the Hollybush sandstone.

We thus obtain glimpses of a main coast-line, two gulfs, or narrow sea-spaces, and two promontories, or islands, during the Cambrian period; but we must wait for more knowledge before we can attempt to realize the connected outlines of this dim and misty scene.

The earth-movements indicated by the lithological changes in the vertical succession of the Cambrian beds are in agreement with the foregoing. The basal conglomerate, and its mode of occurrence, show that the Archæan ridges, which at the commencement of the period raised their summits high above the sea-level, were gradually submerged till the intervening spaces were covered by seas, in which a depth of 10,000 to 12,000 feet of sediment was accumulated (the Harlech, Menevian, and Lower Lingula Flags). The sandy deposits of the Ffestiniog Flags, and their correlatives the Hollybush Sandstones, indicate the setting in of a reverse movement, during which the areas of deposit were narrowed and the ridges broadened by elevation.

The Dolgelly and Tremadoc Beds indicate deeper water, and a second period of depression, which seems to have continued till all the ridges and islands were submerged, and a continuous open sea spread over the whole of England and Wales.

It is also worthy of notice that the supposition of an Atlantic continent, with a coast-line trending south-eastward toward tropical regions, will explain much that is mysterious in the existence of so many different classes of animals in the Lower Cambrian rocks of Wales. For, if we suppose this continent to have had a roughly triangular shape (like modern Africa or America), and to have ended southwards in the equatorial zone, the conditions at its southern termination would be eminently favourable for the evolution and dispersal of life-forms; they would naturally migrate northwards along the coast-lines of the

continent, and would arrive in both the British and American areas about the same period of time. It is at any rate a fact that the fossils found in British and American Cambrians closely resemble one another; and in both countries many distinct and well-marked forms of life suddenly appear on the scene without the previous occurrence of any forms which we could regard as their ancestors.

If, however, these forms were developed in a distant region, and had time for further modification and differentiation during the progress of their migration from that region into the British and American areas, the apparent mystery is to a great extent explained.

Dr. Hicks[1] was, I believe, the first to suggest that "the home of the earliest forms of life seems to have been somewhere towards the south-west, and possibly not far from the equator;" and he remarks in confirmation that the higher invertebrates (Lamellibranchs, Gasteropods, and Cephalopods) appear in the western areas (Spain and Wales) at an earlier period than they do in the north-eastern (Sweden and Russia).

[1] "Quart. Journ. Geol. Soc.," vol. xxxi. p. 555. Hicks, however, supposes the Atlantic to have been an ocean then as now, and the European land to have lain eastward of Britain.

## CHAPTER III.

### ORDOVICIAN SYSTEM.

(LOWER SILURIAN, Murchison and Geological Survey.)
(UPPER CAMBRIAN, Sedgwick.)

*Nomenclature and Divisions.*

THE grounds on which this system has been established have already been explained (p. 57), and in this place it is only necessary to indicate the major divisions or series into which the system has been divided. Here, again, the nomenclatures used by Sedgwick, Murchison, and other geologists are so different that I shall employ the simple terms, Lower, Middle, and Upper, retaining the terms derived from localities for the names of the local groups in each district. The classification in the typical areas will then stand thus :—

ENGLAND.

| | Wales. | Shropshire. | Lake District. |
|---|---|---|---|
| Upper. | Bala Beds. | Caradoc Sandstone. | Ashgill Shales.<br>Coniston Limestone. |
| Middle. | Llandeilo Flags. | Llandeilo Flags. | Borrowdale Series. |
| Lower. | Arenig Slates. | Shelve Beds. | Skiddaw Slates. |

SOUTH SCOTLAND.

| | Moffat Area. | Girvan Area. |
|---|---|---|
| Upper. | Hartfell Shales. | Ardmillan Series. |
| Middle. | Glenkiln Shales. | Stinchar Beds. |
| Lower. | (Not recognized.) | Ballantrae Series (in part). |

*Range and Relation to Rocks below.*

The surface extent of the Ordovician rocks is much greater than that of the Cambrian. They occupy a large

part of Wales stretching continuously from Pembrokeshire through Caermarthen, Cardigan, Radnor, Montgomery, Merioneth, and Denbigh. Passing eastward beneath the lower beds of the Silurian in Montgomery, they rise again to the surface in Shropshire, and form the Corndon and Caradoc tracts, on either side of the Longmynd Hills.

Ordovician fossils were found by Professor Sedgwick in Cornwall, but the stratigraphy of the rocks containing them has not yet been worked out.

Rocks of this age occupy a large part of the Lake District, where they were first studied by Sedgwick. The Isle of Man is an isolated fragment of this Cumbrian area; while, to the eastward, in Yorkshire, some small inlying exposures occur, proving the extension of Ordovician rocks beneath the newer strata in that direction.

In the south of Scotland, Ordovician and Silurian rocks range across from Wigtown to Berwickshire, and form the mass of the southern highlands, their northern boundary being generally the great line of fault which runs from Girvan in Ayr to the Lammermuir Hills. In the north-western highlands Ordovician strata occur at Assynt and Durness, resting upon Archæan and Cambrian rocks, and covered in places by sheets of overthrust metamorphic rocks (see fig. 14). It is believed by some geologists that strata of Ordovician age are included among the metamorphic rocks of the central highlands, but this remains to be proved.

In Ireland there are five principal districts where Ordovician rocks occur: (1) in Wicklow, Wexford, and Waterford, (2) in South Ulster, (3) in North Ulster—Donegal and Londonderry, (4) in Mayo and Galway, (5) in Clare and Tipperary. The first of these areas is opposite the coast of Wales; the second is certainly a continuation of the southern highlands of Scotland; the next two may be regarded as a prolongation of the range of the northern highlands; the last is a group of hill ranges rising from the central plain of Ireland.

Wherever the Upper Cambrian series is present, the lowest member of the Ordovician succeeds in conformable sequence; but whenever the Upper Cambrians are absent, as in south-east Ireland and in Scotland, the Ordovician

rests unconformably either upon Lower Cambrian or Archæan.

As regards their subterranean extension, it is probable that they have a wider spread beneath the overlying strata than any other system in Britain. Originally they must have spread over nearly the whole of the British area; and, as far as we know, the tracts from which they have been removed by erosion are comparatively small.

### *Life of the Period.*

The line of separation between the Cambrian and Ordovician systems is drawn at the base of the Arenig rocks in Wales, because there is a palæontological break between them and the Tremadoc slates; no fewer than forty new genera and 133 new species appear in the Arenig, while only twenty-three genera and sixteen species pass up from the Tremadoc. It is true there is a similar break between the Arenig and Llandeilo faunas, only nine species passing from one to the other; but the two series are united by having many genera of Graptolites and Trilobites in common, the general aspect of the Arenig and Llandeilo fossils being in fact very similar.

The palæontological relations of the three series are shown by the following figures, the numbers after the brackets being the number of species or genera which are common to the bracketed formations.[1]

| | Total of known species. | | Total of known genera. | |
|---|---|---|---|---|
| Tremadoc | 86 | 16 | 33 | 23 |
| Arenig | 150 | 9 | 63 | 33 |
| Llandeilo | 175 | | 80 | |

[1] The generic numbers, 23 and 33, are obtained by deducting the number of new genera, 40 and 47 respectively, from the totals 63 and 80. Mr. Etheridge's tables show only 12 genera passing from the Tremadoc to Arenig and only 8 from Arenig to Llandeilo, but these are merely the genera to which the species passing from one to the other happen to belong; many genera pass besides these.

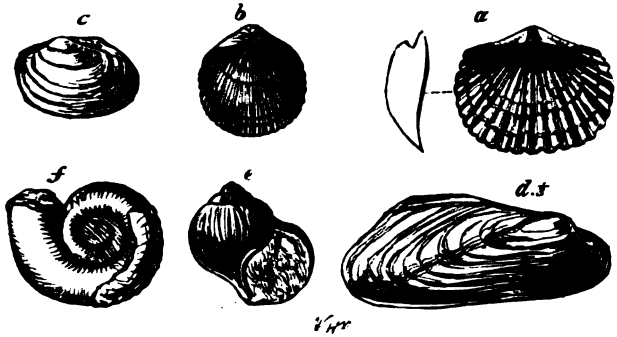



Fig. 7. Mollusca of the Bala Rocks.

*a*. Orthis flabellulum.
*b*. Orthis elegantula.
*c*. Ctenodonta semitruncata.
*d*. Modiolopsis expansa.
*e*. Holopea concinna.
*f*. Lituites Hibernicus.

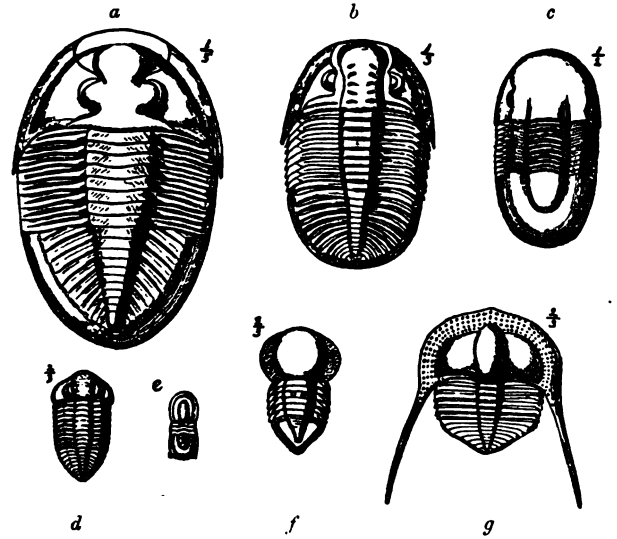



Fig. 8. Ordovician Trilobites.

*a*. Asaphus tyrannus.
*b*. Ogygia Buchii.
*c*. Illænus Davisii.
*d*. Phacops Brongniarti.
*e*. Agnostus trinodus.
*f*. Æglina binodosa.
*g*. Trinucleus concentricus.

Gasteropoda appear in Britain for the first time in the Arenig series, Bryozoa (or Polyzoa) in the Llandeilo, and Actinozoa commence with three species in the Llandeilo limestone. The Echinoderm genera, *Actinocrinus* and *Glyptocrinus*, also appear in the same limestone.

Taken as a whole, the special features of the Ordovician fauna are (1) the abundance of compound Graptolites belonging to the families *Dichograptidæ*, *Dicellograptidæ*, and *Diplograptidæ*; (2) the presence of many peculiar Trilobite genera—*Æglina*, *Ampyx*, *Asaphus*, *Illænus*, *Ogygia*, *Remopleurides*, *Staurocephalus*, and *Trinucleus*; (3) the abundance of Cystideans, eight genera, and twenty-three species, in the Bala group; (4) the abundance of Orthidæ.

The following are the principal species which characterize the Ordovician rocks:—

Fossils of the Lower Ordovician:—

*Rhabdophora.*—Didymograptus patulus, Diplograptus dentatus, Dip. mucronatus, Climacograptus confertus, Phyllograptus angustifolius, Ph. typus, Tetragraptus bryonoides.

*Crustacea.*—Æglina binodosa, Æ. grandis, Ogygia Selwynii, Trinucleus Gibbsii, Calymene parvifrons.

*Brachiopoda.*—Orthis alata, Lingulella acuminata, Obolella plumbea.

*Lamellibranchiata.*—Redonia anglica, Palæarca amygdalis.

*Pteropoda.*—Conularia Homfrayi.

*Cephalopoda.*—Orthoceras sericeum, O. Avelinii.

Fossils of the Middle Ordovician:—

*Rhabdophora.*—Dicellograptus sextans, Glossograptus ciliatus, Dicranograptus ramosus, Diplograptus perexcavatus, Didymograptus Murchisonii.

*Crustacea.*—Asaphus tyrannus, Ampyx nudus, Ogygia Buchii, Trinucleus Lloydii, Tr. Ramsayi.

*Brachiopoda.*—Lingula brevis, Orthis confinis.

*Heteropoda.*—Bellerophon perturbatus, Maclurea Logani.

Fossils of the Upper Ordovician :—

*Rhabdophora.*—Dicellograptus anceps, Dicranograptus Clingani, Climacograptus tubuliferus, Pleurograptus linearis.

*Actinozoa.*—Chætetes petropolitana, Stenopora fibrosa.

*Echinodermata.*—Echinosphærites balticus, Ech. Davisii, Glyptocrinis basalis, Sphæronites Litchi, Sp. stelluliferus.

*Crustacea.*—Trinucleus concentricus, Tr. seticorius, Lichas laxatus, L. Hibernicus, Illænus Davisii, Phacops apiculatus, Ph. Brongniartii, Agnostus trinodus.

*Polyzoa.*—Ptilodictya acuta, Fenestella capillaris.

*Brachiopoda.*—Orthis Actoniæ, O. flabellulum, O. argentea, Strophomena rhomboidalis, Leptæna sericea.[1]

*Lamellibranchiata.*—Ambonychia prisca, Ctenodonta semitruncata, Modiolopsis expansa.

*Gasteropoda.*—Holopea concinna, Cyclonema rupestris.

*Cephalopoda.*—Orthoceras vagans, Lituites Hibernicus.

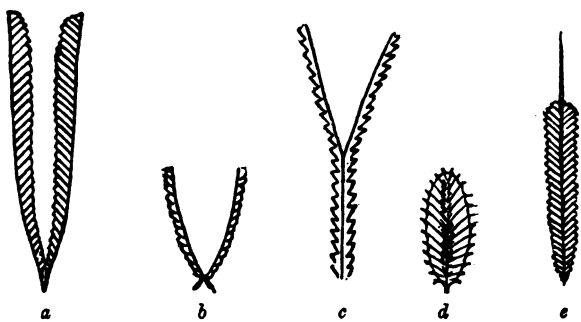



Fig. 9. Ordovician Graptolites.

*a.* Didymograptus Murchisonii. *c.* Dicranograptus ramosus.
*b.* Dicellograptus sextans. *d.* Phyllograptus typus.
*e.* Diplograptus folium.

Professor Lapworth distinguishes the following zones in the British Ordovician rocks, characterized by different species of Graptolites (Rhabdophora).

[1] All these Brachiopods also occur in the Llandeilo rocks.

| | |
|---|---|
| Upper. | Zone of Dicellograptus anceps. |
| | „ Dicellograptus complanatus. |
| | „ Pleurograptus linearis. |
| | „ Dicranograptus Clingani. |
| | „ Climacograptus Wilsoni. |
| Middle. | „ Cænograptus gracilis. |
| | „ Didymograptus Murchisoni. |
| Lower. | „ Didymograptus bifidus. |
| | „ Tetragraptus bryonoides. |

*Stratigraphy.*

1. South Wales.

So much work still remains to be done in the way of tracing the subdivisions of the Cambrian and Ordovician rocks across Wales that it is not yet certain whether the line of separation is drawn at the same stratigraphical plane in both areas. On this account it will be advisable to treat the areas as if they were discontinuous, and to give the succession in each.

**Lower Series (Arenig).**—These have been carefully studied by Dr. Hicks in Pembrokeshire, and the following was his arrangement of the beds in 1875:—

| | Feet. |
|---|---|
| Upper Arenig, black slates . . . | 1,500 |
| Middle Arenig, flags and slates . . | 1,500 |
| Lower Arenig, black slates . . . | 1,000 |

The lower stage contains a mixture of Tremadoc and Arenig species, many Arenig graptolites being associated with *Asaphus Homfrayi*, *Ogygia scutatrix*, *Lingulella Davisii* and *Conularia Homfrayi*. Dr. Hicks regards it as equivalent to the Upper Tremadoc of North Wales, but it is probably a passage group unrepresented in North Wales.

The middle stage contains a typical Arenig assemblage, and probably represents a fuller development of the Garth Grit of North Wales.

The upper stage has since been separated by Dr. Hicks,

under the name of the Llanvirn series, on the ground that the fauna is essentially distinct from the beds below, and that several genera of Trilobites which range into overlying beds here appear for the first time.

**Llandeilo Series.**—North of St. Davids the Llandeilo Flags succeed the Arenig series, and were divided into three stages by Dr. Hicks in 1875.

| | Feet. |
|---|---|
| Upper stage—black slates and flags, with *Ogygia Buchii* . . . . . | 1,000 |
| Middle stage—calcareous slates and flags, with *Asaphus tyrannus* and *Diplograptus foliaceus* . . . . . | 800 |
| Lower stage—black slates and felspathic tuffs, with *Didymograptus Murchisoni* . | 500-1,000 |
| | About 2,500 |

The Llandeilo Flags are found again to the south of the Archæan and Cambrian areas, near Haverfordwest, and thence they range eastwards through Narberth, Caermarthen, and Llandeilo. This district has been recently examined by Messrs. Marr and Roberts, who establish the following succession:—[1]

3. Shales with *Dicranograptus* and *Ogygia Buchii*.
2. Llandeilo limestone with *Asaphus tyrannus*.
1. Shales with *Didymograptus Murchisoni*.

The Llandeilo limestone is best seen at Narberth and Llandeilo, where it is a compact black limestone, but elsewhere it is reduced to a line of calcareous concretions. Besides the *Asaphus*, *Trinucleus flavus*, *Calymene cambrensis*, *Leptæna sericea*, and a few corals, have been found in it.

**Bala Series.**—By Haverfordwest and Narberth the Bala Beds succeed the Llandeilo shales, one passing into the other; the former series comprising the following stages, according to Messrs. Marr and Roberts:—

[1] "Quart. Journ. Geol. Soc.," vol. xli. p. 476.

Fig. 10. Section near Llandeilo (Geological Survey).
Distance about 10 miles.

*a*. Middle Llandeilo. *b*. Upper Llandeilo. *c*. Lower Bala.
*d*. Upper Bala. *e*. Llandovery.

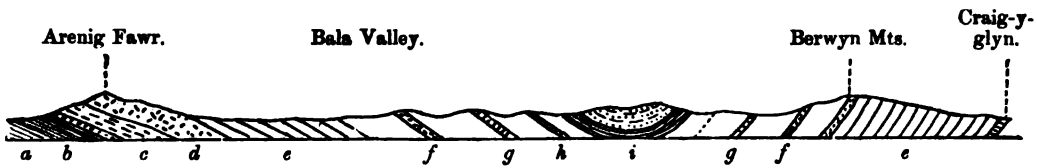



Fig. 11. Section from the Arenig to the Berwyn Mountains.
Distance about 24 miles.

*h*. Hirnant Limestone. *f*. Ash Bed. *d*. Felspathic Lava. *b*. Tremadoc Shale.
*g*. Bala Limestone. *e*. Llandeilo Flags. *c*. Arenig Shale and Grit. *a*. Lingula Flags.
*i*. Tarannon Shale supporting Denbigh Flags.

| | |
|---|---|
| 5. Green shales with calcareous bands, containing *Phyllopora Hisingeri, Trinucleus seticornis.* | = Upper Bala. |
| 4. Grey shales with *Phacops Brongniarti.* | |
| 3. Sholeshook limestone with *Agnostus trinodus, Philipsia parabola, Staurocephalus clavifrons.* | |
| 2. Robeston Wathen limestone | = Bala Limestone. |
| 1. *Dicranograptus* shales, with a zone at the top marked by abundance of *Orthis argentea.* | = Lower Bala. |

Murchison describes the Bala Beds near Llandovery as consisting of dark sandy shales, with some calcareous bands containing *Trinucleus seticornis* and *Staurocephalus Murchisoni.* These beds are overlain by pebbly beds passing up into rocks with Lower Llandovery fossils. It is evident that what Murchison calls Bala Beds here are only the upper part of that series, and that the Lower Bala stage is included in the Llandeilo of the Geological Survey section. When the Graptolites are carefully collected in this district, the boundary between the Llandeilo and Bala series will be more clearly defined. Meantime I reproduce the Survey section, and indicate the probable position of the several stages (see fig. 10).

A similar sequence of Llandeilo, Bala, and Llandovery is also known to occur as far north as Rhyader and Builth.

### 2. North Wales.

**Arenig Series.**—This group was established by Professor Sedgwick, and named from the Arenig mountains in Merioneth; but for many years the relations of the Arenig and Tremadoc series in North Wales remained very uncertain. Mr. Salter, in 1853, did much to unravel the structure of the Portmadoc area and Penrhyn promontory; but it was not till 1874-5 that the base of the Arenigs was finally determined and followed through the typical area by Sir A. Ramsay and other members of the Geological

Survey. They then found that the felspathic grit of Garth and Ty Obrey formed a continuous basement bed, Tremadoc fossils occurring abundantly in the beds below it, and Arenig forms in those above. The passage beds of the Lower Arenig of St. Davids appear to be absent, and the succession of the sedimentary strata appears to be as follows :—

| | | |
|---|---|---|
| Upper Arenig, or Llanvirn Beds. | *b.* | Micaceous shales at Carnarvon. Shales with ash-beds in Arenig Mts. |
| | *a.* | Dark slates underlying the above, with *Ægliua caliginosa*, *Calymene parvifrons*, and *Diplograptus mucronatus*. |

Middle Arenig—Garth Grit.

The Llanvirn beds have been discovered at Llangwyllog in Anglesey, the characteristic Graptolites (see p. 87) occurring in black shales which overlie brown sandstones.

The whole series in North Wales is so largely interstratified with volcanic rocks, that it is difficult to establish any definite succession, or to estimate its thickness. The sedimentary beds are chiefly dark shales and slates; they occur beneath the Snowdon and Carnedd Llewellyn ranges (see fig. 4), and strike southward through the Lleyn peninsula, which is, in fact, a continuation of the great Snowdonian synclinal. They curve round north of the Arenig country, and with thick interstratified sheets of felspathic lava and ash, they form the mountain ranges of the Arenigs, Arans, and Cader Idris.

**Llandeilo Flags.**—Since the whole of the lower series of interbedded volcanic rocks in North Wales is now referred to the Arenig series,[1] it follows that the Llandeilo group must be limited to the dark shaly flags which succeed the volcanic series along the eastern side of the Aran and Arenig ranges. These beds contain very few fossils, and pass gradually up into rocks with fossils of Bala species, so that the very existence of Llandeilo Flags in North Wales is at present rather inferred than actually proved. At Garn, east of Arenig, the following species

[1] Ramsay, "Geology of North Wales," second edition, p. 96.

have been found: *Favosites fibrosa*, *Ampyx mammillatus*, *Orthis Actoniæ*, *O. insularis*, *Leptæna 5-costata* and *Bellerophon bilobatus*. East of the Arans, Selwyn found 5,500 feet of strata between the upper ash and the Bala limestone; some 2,000 feet of this may be Llandeilo, but east of Moel Dhu Jukes found only 4,000 feet between the same limits; some of the beds therefore thin to the northward.

Undoubted Llandeilo beds emerge again in the centre of the Berwyn anticline, and near Llanrhyader the lowest beds are limestones several hundred feet thick, containing *Asaphus tyrannus*, *Trinucleus favus*, *Calymene cambrensis*, *Orthis turgida* and *Orthis verpertilio*. The total thickness of the series in this inlier is estimated by Ramsay at 4,500 feet, and they include some beds of felstone and felspathic ash which cannot be on the horizon of the Arenig rocks, as Ramsay supposes,[1] but are doubtless comparable with those of the Shelve district.

**Bala Series.**—The strata of this series occupy a large area in North Wales; they fill the centre of the Lleyn and Snowdon syncline, and form a continuous tract ranging from Conway in Denbigh southwards by Bala and Dinas Mowddwy. They also form the mass of the Berwyn mountains in South Denbigh, rising up from beneath the Silurian in a huge periclinal dome, and enclosing the Llandeilos of Llanrhyader.

In the typical area (Bala and Berwyn Hills) they consist of the following members:—

| | | Feet. |
|---|---|---|
| Upper. | Shales and Grits | ? 1,000 |
| | Hirnant Limestone and Shales | 26 |
| | Dark Shales | 1,400 |
| Lower. | Bala Limestone, with numerous fossils | 20 to 40 |
| | Slates and Grits | 1,400 |
| | Bed of volcanic ash | 15 |
| | Slates and Grits | 1,600 |
| | | About 5,400 |

Neither base nor summit is yet satisfactorily defined;

[1] Op. cit., p. 300.

the shales and grits above the Hirnant Beds are by some referred to the Lower Llandovery group. Further research is required on this point.

The Bala Limestone commences as a thin band near Dinas Mowddwy, and thickens northwards to 25 feet near Bala, and 40 or 50 feet in the Berwyn mountains, with interstratified shales and a bed of phosphate nodules at its summit. When traced from Bala to the north-west it retains its usual characters as far as Penmachno; but beyond that it is mixed with volcanic ash, and finally passes into a nodular calcarous ash.

In the Snowdon district thick beds of felspathic lava and ash are interstratified with the Bala Beds, greatly increasing the thickness of the series. Apart from this, however, the mechanical sediments thicken westward, being about 8,000 feet in the Aran country, while the limestones increase eastward.

### 3. Shropshire.

Ordovician rocks occur on both sides of the Longmynd (Cambrian) district; but the lower part of the system is only found on the western side in the Shelve and Corndon area, while on the eastern (Stretton and Shineton area) only the Bala Beds are present, resting directly on Tremadoc shales. Fig. 12 is a section across the Shelve area, showing that the series is overstepped by Silurian before the Bala Beds come in.

**Arenig Series.**—The basement beds of the Stiper Stones are hard siliceous grits (? Garth Grit); these pass up into slightly micaceous grey flagstones, succeeded by black shales with fossils—*Ogygia Selwynii, Æglina binodosa, Didymograptus patulus, Lingulella plumbea.* The same series comes again to the surface near Shelve, and Messrs. Lapworth and Hopkinson have collected Graptolites from several localities in that district, which lead them to believe that all three stages of the series are represented. Their total thickness is estimated at 3,000 feet.

**Llandeilo Flags.**—These beds are of a more varied character than those below; at the base are shales and grits, with thick beds of volcanic ash and porcellanic rock

(felspathic), which lie in a syncline east of Shelve, and come in again along the ridge of Stapeley Hill. These are succeeded by thick brownish-green sandstones (with *Ctenodonta* and *Bellerophon bilobatus*), overlain by grey sandstones and dark shales, containing *Asaphus tyrannus* and many other fossils. These are succeeded by black and brown shales, with *Ogygia Buchii* and *Lingula attenuata*, and near the top of this series there are other beds of volcanic ash. The total thickness is estimated by Mr. Morton at 9,000 feet.[1]

**Caradoc Sandstone.**—The Bala series here puts on an arenaceous facies, and was originally described by Murchison under the name of Caradoc Sandstone, from the hills of that name. The Geological Survey still use the combined name of Bala and Caradoc series in their publications. The rocks only occur on the east side of the Longmynd, forming a long narrow strip between it and Wenlock Edge, and extending from the valley of the Clun to that of the Severn near the Wrekin. The vertical succession given by Murchison,[2] and taken from the sections of the Geological Survey, is as follows:—

Llandovery Beds (unconformable).

| | |
|---|---|
| Caradoc Sandstone, 4,000 feet. | Shales with *Trinucleus*. |
| | Cheney Longville Flags. |
| | Chatwell Sandstones. |
| | Soft Shales. |
| | Hoar Edge Grits. |

Sandy Shales (? Tremadoc).

In the Shineton area, further north, only the lower part of the above is found according to Dr. Callaway, the upper beds being probably concealed beneath the Llandoveries.

Llandovery Sandstone.

| | |
|---|---|
| Caradoc Sandstone. | Chatwell Sandstone. |
| | Harnage Shales. |
| | Hoar Edge Grits. |

Shineton Shales (Tremadoc).

[1] "Geology of the Country around Shelve," Proc. Liverpool Geol. Soc., 1868-9.

[2] "Siluria," fourth edition, p. 66.

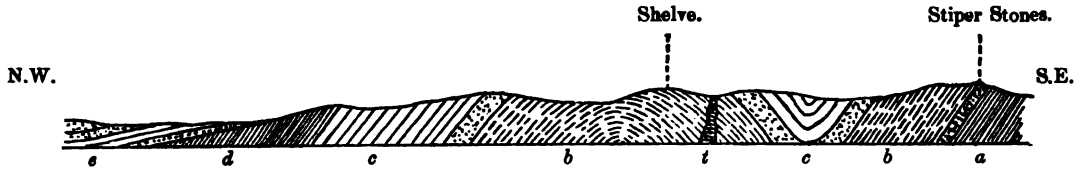



Fig. 12. Section across the district of Shelve (Morton).

*a*. Tremadoc Shales.
*b*. Arenig Beds.
*c*. Llandeilo Flags.
*d*. Llandeilo Shales.
*e*. Silurian Beds.
*t*. Trap dyke.

Fig. 13. Generalized Section across the Lake District from the Solway to Kirkby Lonsdale.
Distance about 60 miles.

*n*. Trias.
*m*. Coal-Measures, &c.
*k*. Carb. Limestone.
*g*. Ludlow Beds (Clunian).
*f*. Wenlock Beds (Salopian).
*e*. Valentian Shales.
*d*. Coniston Limestone.
*c*. Borrowdale Series.
*b*. Skiddaw Slates.
*a*. Granite, &c.

For the above section I am indebted to Mr. J. G. Goodchild.

### 4. The North of England.

Ordovician rocks occupy a large area in the Lake District, which was the scene of Professor Sedgwick's earliest work on the rocks of this system (1832-36). All the mountainous region lying north-west of a line drawn from the estuary of the Duddon, by Hawkshead and Ambleside, to the valley of the Lowther Beck, consists essentially of Ordovician rocks (see fig. 13).

**Lower Series** (Skiddaw Slates).—It was mentioned on p. 73 that the lowest beds which were formerly included in this series may possibly be of Upper Cambrian age. The late Mr. C. Ward believed the grit beds of Gatesgarth, Lutterbarrow, and Tongue Beck to be the equivalent of the Garth grit of North Wales, and he therefore took these as the basement beds of the series. The grits are succeeded by no less than 7,000 feet of black slates, which contain about forty species of Graptolites, the chief of which are *Didymograptus patulus, D. bifidus, Diplograptus mucronatus, Phyllograptus typus, Tetragraptus crucifer, T. bryonoides*, with *Æglina binodosa, Æ. caliginosa, Trinucleus Gibbsii*, &c.

**Middle Series** (Borrowdale Group).—The Skiddaw slates are succeeded by a great series of volcanic rocks—lavas and ashes—not less than 12,000 feet thick. The greater part of these rocks must have been formed during the deposition of the Welsh Llandeilo beds, but the uppermost portion may be of Bala age, for in the Pennine area (Dufton), there are some 300 feet of black shale, replacing the topmost volcanic rocks, and containing *Illænus Bowmanni, Trinucleus seticornis, Leptæna sericea, Orthis testudinaria;* and *Lingula ovata*.

**Upper Series** (Coniston Limestone Group).—This usually consists of grey limestone with beds of shale, but in some places it passes into massive white and pink limestones. Its fossils are similar to those of the Bala limestone; but higher beds occur in certain localities, notably at Ashgill, consisting of grey limestone overlain by black and blue shales, which contain some fossils not found below, such as *Caryocystites Davisii, Staurocephalus clavifrons, Holopea concinna*, and *Orthoceras vagans*.

### 5. South Scotland.

Our knowledge of this region is mainly due to the researches of Professor Lapworth, who has carefully described the two areas where fossils are most abundant, namely, the neighbourhood of Girvan in Ayrshire, and that of Moffat in Dumfries.[1] The following is a comparative view of the succession in each area:—

| | Girvan. | Moffat. |
|---|---|---|
| Upper Series, 3,000 feet. | Drummuck group.<br>Barren flags.<br>Whitehouse group. | Upper Hartfell shales (50 feet). |
| | Ardwell group.<br>Balclatchie Beds.<br>Benan conglomerate. | Lower Hartfell shales (45 feet). |
| Middle Series. | Stinchar limestone.<br>Kirkland conglom. | Glenkiln shales (60 feet). |
| Lower Series. | Ballantrae rocks. | Base not seen. |

**Lower Series.**—The stratigraphy of the Ballantrae rocks has not yet been worked out; it is a complicated group of igneous and sedimentary rocks, pierced by intrusive gabbros and serpentines, &c.; but Professor Lapworth informs me that in some places it contains black shales, which yield Graptolites of Arenig and Skiddaw forms—*Tetragraptus bryonoides*, *Phyllograptus*, and *Didymograptus Murchisoni*.

**Middle Series.**—No beds comparable with the Lower Llandeilo have yet been recognized. The Ballantrae series is succeeded by the Barr or Stinchar group, the lowest member of which is a purple conglomerate full of rounded masses of igneous rocks embedded in a matrix of sandy and calcareous matter. This is succeeded by purple sandstones and grits, the whole group being about 150 feet thick, but without any organic remains. The next group is that of the Stinchar limestone, which consists of three members—(a) calcareous flagstones with *Orthis confinis*, (b) limestones with many fossils, (c) shales with *Didymo-*

[1] "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 240, and vol. xxxviii. p. 538.

*graptus superstes* and other fossils. The fossils of the limestone are peculiar and interesting, some being characteristic of the Trenton limestone in Canada, but not occurring in any English rock; such are *Maclurea Logani* and *M. magna*, *Tetradium* (a coral-like sponge), and *Murchisonia angustata*. These occur with many corals, and *Lichas Hibernicus*, *Illœnus Bowmanni*, and *Calymene Blumenbachii*, which are common to Llandeilo and Bala Beds. The shales above contain some fossils which occur again in the Balclatchie Beds, and appear to form a transitional zone between the two series.

In the Moffat area no base has yet been found, but the Glenkiln group is clearly of the same general age as the Stinchar limestone; it consists of barren mudstones, with a zone of graptolitic shale at the top, containing *Didymograptus superstes*, *Cœnograptus gracilis*, *Dicellograptus sextans*, and others.

**Upper Series.**—This in the Girvan area commences with a massive boulder conglomerate, having a greenish sandy or ashy matrix, and varying from 500 to 1,000 feet in thickness. Above this are the Balclatchie Beds, consisting of mudstones and grits, with many fossils, among which are *Phacops Brongniarti* (abundant), *Asaphus gigas*, *Stygina latifrons*, *Remopleurides latero-spinifer*, *Agnostus trinodus*, *Staurocephalus globiceps*, *Cybele verrucosa*, and *Sphærexochus mirus*.[1]

Above these beds is a thick series of shales, flagstones, and mudstones, named the Ardmillan series by Professor Lapworth, and divided into four groups (as above), which are characterized by the following Graptolites:—

D. *Dicellograptus anceps*, *Diplograptus truncatus*.
C. Barren.
B. *Pleurograptus linearis*, *Diplograptus socialis*.
A. *Dicranograptus ramosus*, *Climacograptus caudatus*.

At the base of the Ardwell group are shales with

[1] Professor Lapworth regards these beds as a transitional group between the Barr and Ardmillan series, because some of the fossils occur also in the Stinchar limestone, but I prefer to take the Benan conglomerate as the base of the Bala rocks in S.W. Scotland.

*Climacograptus Scharenbergi*, which is also found in the underlying Balclatchie Beds.

The Whitehouse group also contains Trilobites of the genera *Dionide*, *Asaphus*, *Agnostus*, *Trinucleus*, and *Cyclopyge*; while the highest mudstones have *Trinucleus seticornis*, *Staurocephalus globiceps*, and *Ampyx rostratus*, with *Palæaster* and other fossils.

Professor Lapworth's researches in the Moffat district bring out the remarkable fact that all these Bala strata are represented by no more than about 100 feet of black shale; yet the same graptolite zones are found compressed into this small space and by this means the beds of the two areas can be accurately correlated, the Upper Hartfell corresponding to the Drummuck and Whitehouse groups, and the Lower Hartfell to the Ardwell and Balclatchie groups.

### 6. North Scotland.

The only districts which have yet been thoroughly investigated are those of Durness and Eriboll in Sutherland, and the following account is taken from the report of Messrs. Peach and Horne.[1]

The beds of the Durness area are arranged in the form of a basin truncated on the eastern side by a fault which brings them against the Archæan gneiss (see fig. 14); on the west they are seen to rest unconformably on this gneiss and on the red Torridon sandstone. The Durness basin is separated from that of Loch Eriboll by a prominent ridge of Archæan gneiss, which, however, bears an outlier of the Ordovician basement beds. The Eriboll area exhibits the same series as that of Durness, but they are crushed and faulted in a remarkable manner, and are cut off on the east by a *thrust-plane*, which actually carries some of the Archæan gneiss over the newer Ordovician series, so that here the ordinary test of age by superposition becomes useless. This superposition of Archæan on Ordovician can be clearly seen at Ben Arnaboll.

The total thickness of the Ordovician rocks seen in these two areas is estimated at 2,000 feet, composed as follows:—

[1] "Nature," 1884, vol. xxxi. p. 31.

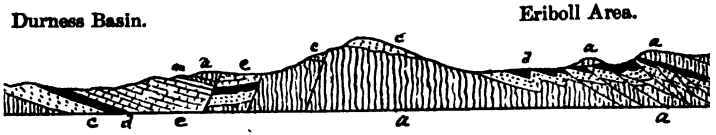



Fig. 14. Generalized Section across the Durness-Eriboll Region of Sutherl
(after Messrs. Peach and Horne).

*m*. Siliceous Schists. *d*. Calcareous Grits and Mudstor
*f*. Frilled Schists. *c*. Quartzite Group,
*e*. Limestone Series. *b*. Torridon Sandstone.
*a*. Archæan Gneiss.

ɔe noticed that the faults in the western half of the section are of the normal ki
w, while those in the eastern half are all reversed overthrust faults or thrust-pl

| | |
|---|---|
| C. Calcareous Series (very thick). | 3. Light and dark grey limestones, with many fossils at certain horizons.<br>2. Granular dolomites and dolomitic limestones.<br>1. Limestones and calcareous shales, with dark limestones at the base. |
| B. Middle Series (thin). | 3. Dolomitic grit, with *Serpulites*.<br>2. Brown grits and quartzites, with shales.<br>1. Calcareous mudstones, with worm-casts. |
| A. Lower Series (thin). | 2. Massive quartzites, with worm-casts.<br>1. Grits and quartzites, with a basement bed of brecciated conglomerate. |

A rich assemblage of fossils has been obtained from the limestones, but the lists are not yet published.

### 7. IRELAND.

The palæontology of the Irish Ordovician rocks has not yet been studied with the same care that has been bestowed upon the Welsh rocks by Dr. Hicks and upon the Scotch series by Professor Lapworth. We are, therefore, unable to give anything like a complete account of the Ordovician system in Ireland.

**Lower Series.**—No rocks comparable to the Welsh Arenigs have yet been found in Ireland.

**Middle Series.**—Rocks of Llandeilo age have been identified in several localities, and are known as the "Dark Shale Series." They occupy the coast south of Wicklow, and are well exposed in the cliffs of Ballymoney, near Courtown, and thence strike through Wexford and Waterford to Tramore Bay. They consist of blue and black shales, with flaggy grits, and contain *Dicellograptus sextans*, *Cœnograptus gracilis*, *Diplograptus foliaceus*, *Dicranograptus ramosus*, and *Leptograptus flaccidus*, which prove them to be on the horizon of the Glenkiln Shales.

The same beds occur at Slieve Bernagh, co. Clare, where Mr. Baily found most of the above species; and also in co. Down, south of Belfast Lough, where Mr. Swanston has obtained all the characteristic Graptolites of the Glen-

kiln group. A smaller area is found in Meath, running inland from the coast near Balbriggan.

In co. Meath (Bellewston Hill) there are beds belonging to a lower horizon, and yielding *Didymograptus Murchisoni*.

In South Mayo and Galway there are shaly rocks, with fossils of Llandeilo age, 1,000 feet thick, and overlaid by beds with contemporaneous volcanic rocks, which may be of Bala age.

**Upper Series.**—This is known as the Ballymoney series, and overlies the Dark Shale series at Ballymoney and elsewhere in Wicklow, Wexford, and Waterford. In this area it contains *Phacops Brongniarti*, *Lichas laxatus*, *Trinucleus concentricus*, and *Illœnus Bowmanni*.

At Portraine on the Dublin coast there is one of the finest sections of the Coniston Limestone and its associated rocks to be found in the British Islands. Ash-beds and lavas comparable to the Borrowdale Beds are succeeded by green shales with calcareous nodules, which pass by gradations into a calcareous group containing massive limestones, with fossils of the Coniston Limestone. This locality is exactly on the line of strike of the Lake District exposures, and the same line prolonged carries us south-west into Kildare, where the range of hills, called the Chair of Kildare, consists of the same rocks, including limestone, with abundance of fossils.

In Clare and Tipperary, on either side of the river Shannon, there are several tracts of Ordovician rock, forming the Cratloe Hills, Slieve Bernagh, and Slieve Aughta, in Clare; Slieve Phelim, and Keeper Mountain, and Slieve Arra, in Tipperary. The equivalents of the Bala or Ballymoney series are largely developed, and near Ballycar they appear to pass up into beds with Silurian fossils (? Lower Llandovery).

From black shales in co. Down Mr. Swanston has obtained the following Graptolites amongst many: *Dicranograptus Clingani*, *Diplograptus truncatus*, *Climacograptus Scharenbergi*, *Cl. bicornis*, and *Dicellograptus caduceus*; and this tract strikes south-westward through Armagh, Monaghan, and Cavan. At Pomeroy in Tyrone there is a small but important tract of rock, from which many Bala fossils have been obtained.

### 8. Scandinavia.

The Ordovician rocks of Norway and Sweden are of more importance to British geologists than those of other European countries, but space only permits of a brief account of them.

The lowest member of the series is a limestone rich in fossils, especially *Orthoceras* and its allies, whence it is known as the Orthoceras Limestone; associated with it are shales containing *Phyllograptus typus*. These may be of Arenig age.

In Scania the above are succeeded by shales with Graptolites, the three lower zones of which appear to represent our Llandeilo series; and the three upper our Lower Bala beds. They are—

6. Zone of Orthis argentea.
5. „ Dicranograptus Clingani.
4. „ Climacograptus Scharenbergi.
3. „ Diplograptus mucronatus.
2. „ Glossograptus Hincksii.
1. „ Didymograptus geminus.

Some of these shales are represented by limestones in other districts.

The highest group consists of shales with *Trinucleus seticornis*, limestone with *Staurocephalus clavifrons*, and shales above, but these upper beds are not always present.

#### *Volcanic Rocks.*

Rocks of volcanic origin play a prominent part in the records of this system. As the ashes and lavas are interstratified with fossiliferous marine strata, it is probable that the eruptions took place either from submarine vents or from groups of volcanic islands, such as occur in the Pacific Ocean of the present day.

In Wales these outbursts commenced in Arenig times, that series containing thick lenticular masses of felspathic lava and ash (see fig. 4, p. 67). These interbedded masses are thickest in Cader Idris and Aran Mowddwy, but thin

away rapidly both to the north and south of this district. At Aran Mowddwy their united thickness amounts to 5,200 feet, at the north end of the Aran range it is reduced to 2,350 feet, and in the Arenig mountains to 1,050 feet; west of Tremadoc they disappear entirely. Sir A. Ramsay [1] indicates the great boss of Rhobell Fawr, with its ashy agglomerates, as one of the centres of eruption. In most text-books all these volcanic rocks are referred to the Llandeilo series, because until recently the Geological Survey included the Arenig rocks in that series, and termed them "Lower Llandeilo." Now, however, in the new edition of the "Memoir on North Wales" (1881), it is expressly stated (p. 96) that "the whole of the lower interbedded igneous series is included in the Arenig beds of Professor Sedgwick;" the upper igneous series being that of the Bala rocks. In the Berwyn Hills, however, and in Shropshire, there are thick beds of ash in the Llandeilo series (see figs. 11 and 12).

After a period of repose volcanic activity was renewed; the normal development of the Bala rocks has been described on p. 93, but north of Moel Siabod the series assumes a very different character from the interpolation of numerous beds of felstone and volcanic ash. "These range northward to Conway, and from thence south-westward along the higher Caernarvonshire mountains. Carnedd-Llewellyn, Carnedd-Dafydd, Y-Glyder-fach, Y-Glyder-fawr, Snowdon, and Moel-Hebog are the chief mountains in this the highest, wildest, and grandest part of North Wales; and these consist in a great degree of true volcanic products, some of which are interbedded, and some of the intrusive masses may be the deep-seated centres of volcanic eruptions." [2] As shown in fig. 4, the Snowdon range occupies the western side of a complicated synclinal flexure, which is continued throughout the promontory of Lleyn. The structure of the range is as follows: upon the Bala slates and grits lie three great beds of porphyritic felstone, which southward converge into one mass; these are succeeded by beds of felspathic, sandy, and calcareous ash,

[1] "Geology of North Wales, Mem. Geol. Survey," second edition, p. 98.

[2] Ramsay, "Geology of North Wales," second edition, p. 130.

some of which contain fossils, and are supposed to represent the Bala limestone; the ash-beds are capped here and there by the relics of another sheet of felspathic lava, which has been nearly all removed by subsequent erosion. The total thickness of these accumulations is over 3,000 feet, being as follows:—

| | Feet. |
|---|---|
| Columnar felstone . . . . . | 200 |
| Ashy beds . . . . . | 1,200 |
| Porphyritic felstones . . . . | 1,700 |

Some of the Bala felstones have been studied by Professor Bonney and others by Mr. Rutley, and prove to be devitrified rhyolites, exhibiting fluxion structure under the microscope; some are spherulitic, and others have a peculiar nodular structure.[1]

In the Lake District the Borrowdale group, which is probably of Llandeilo age, consists mainly of volcanic rocks —a series of andesitic lavas, ashes, and agglomerates of green or purple colours, which were termed the "Green slates and Porphyries" by Professor Sedgwick. The cleavage which traverses the district converts some of the finer ash-beds into regular slates, as seen in the quarries at Dale Head. A similar series is found in the Isle of Man.

In Ireland, felstones, gabbros, tuffs, and agglomerates occur in the Llandeilo series of Wicklow and Wexford; porphyritic felstones and ash-beds of the Borrowdale type appear near Portraine, co. Dublin.

### *Physical Geography.*

The general depression and sinking of the whole British area, which commenced in later Cambrian times, continued during the Ordovician, and the sea appears to have spread over nearly the whole of England, Ireland, and Scotland, except perhaps the extreme south-east portion of England. The downward movement seems to have culminated in the Llandeilo and Lower Bala periods, when nothing but fine muddy and silty sediment was thrown down everywhere,

[1] See Bonney, "Quart. Journ. Geol. Soc.," vol. xxxviii. p. 289, and Rutley, op. cit., vol. xxxvii. p. 403.

except in the Lake District, which appears at that time to have been the site of a group of volcanic islands.

As we rise through the Bala series, sandy beds and volcanic rocks again appear, and the Caradoc sandstone of Shropshire and South Wales is a proof of the lessening depth of the water in those areas. Islands, such as that of the Longmynd, began to rise above the waves, and it is probable that considerable tracts of Cambrian and Ordovician rocks were elevated into land before or at the commencement of the ensuing Silurian period.

Such was the succession of events in England, but we know that there must have been land somewhere during the whole of the Ordovician period, for the mechanical sediments could only have been derived from the waste of land, and this could not have been very far away, since it supplied the material for more than 10,000 feet of rock. Can we indicate the position of this land? There is every reason to suppose that it occupied the same position as in Cambrian times, namely, the area which is now the North Atlantic Ocean, but its margin appears to have been entirely outside Ireland.

Islands may have existed at all times in this Britannic ocean, but especially in the later part of the period. The westward increase in the Bala sediments of North Wales, and the easterly increase in the limestones, is probably indicative of some large island to the west of Wales, just as the Caradoc sandstone indicates land to the eastward. We may therefore imagine the Bala limestone to have been formed in a deep strait between two large islands.

Another important fact is the entire absence of Ordovician rocks near Malvern, where the Silurian beds rest unconformably on Cambrian, or on an interposed sheet of hornblendic lava. We cannot doubt that this area was also land during part of the period under review, and for aught we know it may have had a considerable extension northward and eastward, for we have no evidence yet of the existence of Ordovician rocks in central England.

The close correspondence between the Ordovician rocks of Britain and Scandinavia proves that the two areas formed part of one zoological province, and that there was continuous sea between them.

## CHAPTER IV.

### Silurian System.

(Upper Silurian of Murchison and Geological Survey.)

*Nomenclature and Divisions.*

The reasons for restricting the name *Silurian* to the system called Upper Silurian by Murchison have been given on p. 58, but no mention was there made of a subordinate question, namely, the line of separation between the so-called Upper and Lower Silurian. Originally the whole of the strata subsequently called Llandovery Beds were included by Murchison in his Upper Caradoc group, but in 1854 Professors Sedgwick and McCoy proved that the uppermost sandstones (to which they gave the name of May Hill Sandstone), had no connection physically or palæontologically with the Bala rocks, but formed the natural base of Murchison's (Upper) Silurian series in the typical Silurian areas.

Recognizing the justice of this correction, Murchison then separated the beds from the Caradoc Sandstone (Bala), and created a new group under the name of "Llandovery Rocks," subdividing it into two stages—a lower (linked by some species to the Bala series), and an upper (closely connected with the Wenlock rocks), but clearly united to one another by a community of *Pentameri* and other fossils. This Llandovery group he regarded as forming a transition series between his Lower and Upper Silurian.

Some geologists, however, objected to this arrangement on the ground that there is frequently a physical break (overlap leading to unconformity) between the Lower and Upper Llandovery, so that the latter in such localities is dissociated altogether from the former and from the Bala Beds. Consequently, Sedgwick, Jukes, and others drew

the line of separation at the base of the Upper Llandovery or May Hill Sandstone. But elsewhere there is little or no want of conformity between the members of the Llandovery, while the Lower Llandovery is locally transgressive over the Bala Beds. It follows, however, from the principles laid down in Part IV., Chap. III., that small regard must be paid to such local transgressions and unconformities, unless they coincide with a palæontological break. Murchison therefore was right in uniting the two Llandoveries on palæontological grounds, and when all the original confusion between the Caradoc and Lower Llandovery sandstones has been eliminated, it will probably be found that the number of Bala species in the latter is much smaller than the number of species uniting it to the Upper Llandovery.

Recent researches have shown that the Upper Llandovery is usually succeeded by a series of pale grey and green shales (Tarannon Shales), and Professor Lapworth's studies have led him to the conclusion that these three subdivisions (Lower Llandovery, Upper Llandovery, and Tarannon Shales), "are far more closely allied to each other than they are to the beds above or below, and that they should be considered as the three consecutive members of a single formation."[1] The Llandoveries were formed in fact during a period of upheaval and oscillation which intervened between the quiet periods of the Bala and Wenlock Beds. The rocks have a common character distinct from these formations, and the fauna as a whole shows corresponding peculiarities. For their equivalents in South Scotland, he has proposed the name *Valentian*, from the Roman name of the province, and Mr. Marr[2] has advocated the general adoption of this name for the lowermost group or series of the Silurian rocks in Britain.

"The second natural division of the Silurian system is undoubtedly Murchison's Great Mudstone series, which includes the so-called Wenlock and Lower Ludlow groups. . . . . In Shropshire this great mudstone or Salopian for-

[1] "On the Geological Distribution of the Rhabdophora, Ann. Mag. Nat. Hist.," ser. v., vol. iii.

[2] "Classif. of Camb. and Sil. Rocks, Sedgwick Prize Essay," 1883, p. 117.

mation is by far the most important physical group in the Silurian."[1] Murchison drew the line of demarcation between his Wenlock and Ludlow groups at the top of the Wenlock limestone, but he admits[2] that the Lower Ludlow is only an upward prolongation of the Wenlock shale, and that his chief reason for grouping it with the Ludlow was that it forms the base of the ridges which are capped by the Aymestry limestone. Palæontologically the shales appear to belong to the Wenlock, but just below the Aymestry limestone there is a set of thick bedded earthy flagstones which contain Cephalopods and Starfish in some abundance. It would seem, therefore, that the line between the Wenlock and Ludlow Beds should be drawn here, and I agree with Prof. Lapworth that "the natural boundary is at the summit of the Great Mudstone group (a little below the line of the Aymestry limestone), where new physical conditions set in, and the rocks contain a comparatively new fauna." To the mudstone group we may apply the term *Salopian*.

In the typical districts the uppermost Silurian group consists of the Leintwardine Flags, the Aymestry Limestone, the Upper Ludlow Beds, the Downton Sandstone and the Tilestones which pass into the Old Red Sandstone. For this series the name Downtonian has been used, but the author has elsewhere suggested Clunian (from Clun Forest) as a better designation.

Murchison's subdivisions will therefore be grouped under three heads, as follows:—

| | | |
|---|---|---|
| Silurian System. | Ludlow, or Clunian. | Tilestones and Downton Sandstone. |
| | | Upper Ludlow Beds. |
| | | Aymestry Limestone. |
| | | Leintwardine Flags. |
| | Wenlock, or Salopian. | Lower Ludlow Shales. |
| | | Wenlock Limestone. |
| | | Wenlock Shale and Woolhope Limestone. |
| | Llandovery, or Valentian. | Tarannon Shales. |
| | | May Hill Sandstone. |
| | | Lower Llandovery Beds. |

[1] Lapworth, loc. cit. [2] "Siluria," fourth edition, pp. 122, 124.

*Range and Relation to Rocks below.*

In South Wales the Silurians emerge from beneath the overlapping Carboniferous strata west of Narberth, and form a narrow strip (the beds being nearly vertical) for a long distance between the Ordovician and Old Red Sandstone areas. Near Builth the inclination becomes less, and the Silurian area widens rapidly, till in the Radnor and Clun Forest districts it has a width of from twelve to twenty-five miles. Moreover, a prolongation of the great Caradoc fault repeats the series along a tract extending from Presteign by Wenlock Edge to Coalbrookdale. From Radnor the main outcrops run through Montgomery, but the periclinal dome of the Berwyn mountains separates them from the Silurians of Denbighshire, which occupy the country between the valleys of Dee, Clwyd, and Conway.

In the south-east of Wales (Cardiff and Usk), as well as at Malvern and other localities in Gloucester, Hereford, and Worcester-shires, the Silurians are brought up again to the surface by anticlinal or periclinal flexures, forming isolated tracts, surrounded on all sides by younger rocks. Other such inlying exposures occur in Staffordshire, at Dudley, Sedgley, and Walsall; and Silurian rocks have recently been proved to occur beneath the Cretaceous beds in Hertfordshire; it is probable, therefore, that they have a very considerable subterranean extension in the centre and east of England.

In the Lake District the Silurian rocks lie to the south-east of the Ordovician region in Westmoreland, reaching from the estuary of the Duddon by Coniston water and Windermere to the valley of the Kent north of Kendal, occupying the upper valley of the Lune as far south as Kirkby Lonsdale in Lancashire.

In Scotland Silurians occur along with the Ordovician, both in the Highlands and in the Border region; but it is not yet possible to indicate the areas they separately occupy. Wenlock Rocks (the Riccarton Beds of Lapworth) extend in a long strip from Kirkcudbright to the Cheviot Hills. Fossiliferous strata of both Wenlock and Ludlow age occur in the Pentland Hills, and Ludlow rocks occur in Lanark.

On geological maps of Ireland Silurian rocks are only shown in the extreme west (Mayo, Galway, and the Dingle promontory); but Graptolites indicating rocks of Valentian age have lately been found in counties Down and Dublin.

In England and the west of Ireland the Silurian rocks are generally more or less unconformable to the Ordovician, the lowest members being generally coarse sandstones and shore deposits, which (as is usual with such deposits) are very irregularly developed, and are sometimes locally unconformable to one another.

In Dumfriesshire and N.E. Ireland, on the other hand, the lower beds (Valentian) are of a deep-water character, and exhibit a complete passage from one system into the other. In the Girvan district shallow and deeper water-beds alternate with each other, and there appear to be local unconformities.

### *Life of the Period.*

Compared with Ordovician life, the Silurian assemblage is characterized by (1) the exclusive presence of the *Monograptidæ*, none of the component genera *Monograptus*, *Cyrtograptus*, and *Rastrites* being known in the Ordovician; (2) the abundance of Actinozoa (Corals), no less than 76 species occurring in the Wenlock Limestone; *Acervularia*, *Alveolites*, *Cyathophyllum*, *Clisiophyllum*, *Cystiphyllum*, all date from Silurian times; and *Labechia*, *Thecia*, *Palæocyclus*, *Goniophyllum*, *Omphyma*, and *Aulacophyllum* are confined to these rocks; (3) the abundance of Echinoderms, especially Crinoids and Cystideans, of which there are 68 species in the Wenlock Beds. *Cyathocrinus*, *Platycrinus*, *Taxocrinus*, and *Palæchinus* commence their existence, while *Crotalocrinus*, *Marsupiocrinus*, *Enallocrinus*, *Ichthyocrinus*, *Apiocystites*, *Echinoencrinus* and *Pseudocrinites* do not occur out of Silurian beds so far as is yet known.

Of Crustacea only three new genera of Trilobites make their appearance, viz., *Deiphon*, *Proëtus* and *Cyphaspis*; but the first forms of Eurypteridæ occur—*Eurypterus*, *Pterygotus*, *Hemiaspis*, and *Slimonia*. Brachiopods are very abundant, and the genera *Athyris*, *Chonetes*, *Pentamerus*, and

*Retzia* have their first known representatives. Of Lamellibranchs *Cardiola*, *Ctenodonta*, *Grammysia*, *Cucullella* and *Pterinæa* are the principal genera. Among Cephalopods many new and curious forms appear, such as *Actinoceras*, *Ascoceras*, *Gomphoceras*, *Phragmoceras*, and *Trochoceras*.

Vertebrate animals in the form of fishes make their first appearance in the Ludlow rocks, the genera *Auchenaspis*, *Cephalaspis*, *Pteraspis*, *Plectrodus*, and *Sphagodus* (all belonging to the order *Ganoidei*) occurring at that horizon.

The following are some of the species which are specially characteristic of the three great groups or series in the Silurian system.

## Fossils of the Valentian (Llandovery).

*Rhabdophora.*—Diplograptus folium, Climacograptus normalis, Monograptus gregarius, M. Sedgwickii, Rastrites peregrinus, R. maximus.

*Actinozoa.*—Petraia bina, Lindstræmia subduplicata, and many others which range up into Salopian beds.

*Crustacea.*—Proëtus Stokesii, Acidaspis Brightii.

*Brachiopoda.*—Atrypa hemispherica, Orthis reversa, Meristella crassa, M. angustifrons, Rhynchonella neglecta, Pentamerus oblongus, Stricklandia lens.

*Lamellibranchiata.*—None of special interest.

*Gasteropoda.*—Euomphalus prenuntius, Holopella plana, Murchisonia angulata.

*Cephalopoda.*—Cyrtoceras approximatum, Tretoceras bisophonatum, Orthoceras conicum.

## Fossils of the Salopian (Wenlock).

*Hydrocorallina.*—Stromatopora striatella.

*Rhabdophora.*—Monograptus priodon, M. colonus, M. vomerinus, Cyrtograptus Murchisonii.

*Actinozoa.*—Omphyma turbinatum, Acervularia luxurians, Alveolites Labechii, Heliolites Grayi, H. interstinctus, Favosites Gothlandicus, Strombodes diffluens, Cyathophyllum truncatum.

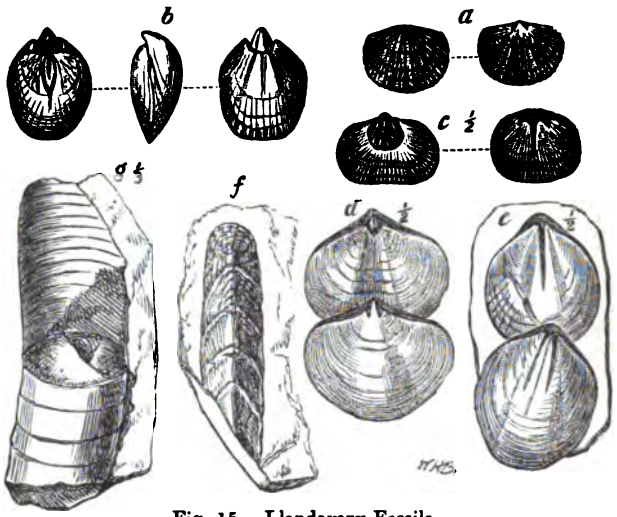



Fig. 15. Llandovery Fossils.

*a*. Atrypa hemispherica.
*b*. Meristella angustifrons.
*c*. Orthis reversa.
*d*. Stricklandinia lens.
*e*. Pentamerus oblongus.
*f*. Chiton Griffithii.
*g*. Cyrtoceras approximatum.

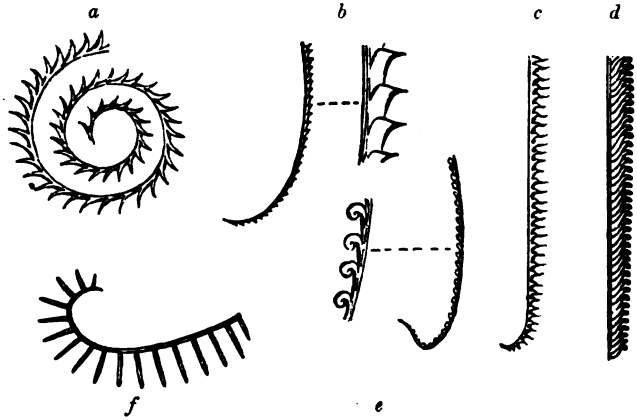



Fig. 16. Silurian Graptolites.

*a*. Monograptus spiralis.
*b*. ,, gregarius.
*c*. ,, Sedgwickii.
*d*. Monograptus priodon.
*e*. ,, exiguus.
*f*. Rastrites peregrinus.

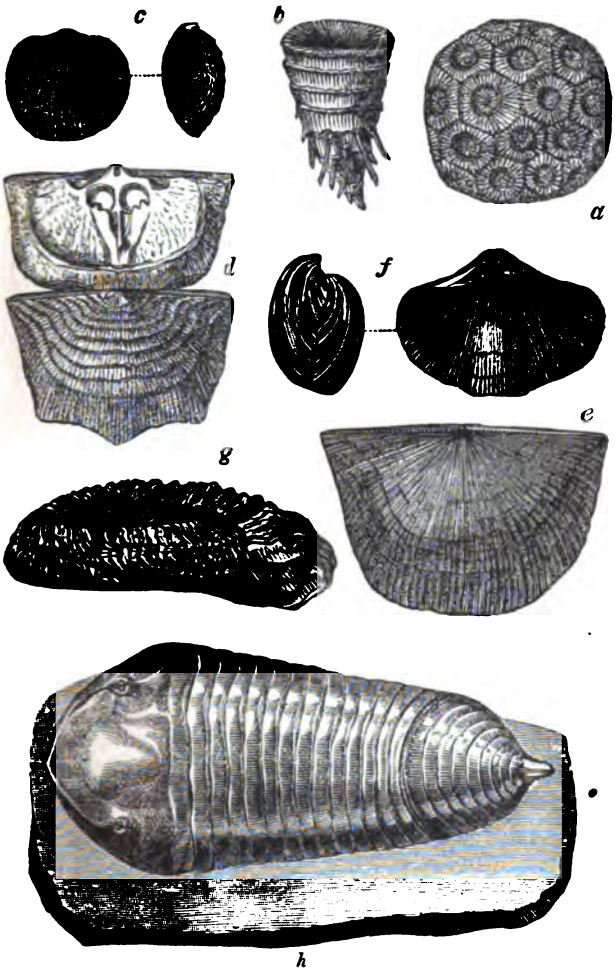



Fig. 17. Salopian Fossils.

*a*. Acervularia luxurians.
*b*. Omphyma turbinatum.
*c*. Atrypa reticularis.
*d*. Strophomena depressa.
*e*. Strophomena euglypha.
*f*. Spirifer plicatellus.
*g*. Euomphalus discors.
*h*. Homalonotus delphinocephalus.

*Crustacea.*—Phacops caudatus (from Bala), Calymene Blumenbachii (from Bala), Illænus Barriensis, Lichas anglicus, Homalonotus delphinocephalus.

*Echinodermata.*—Crotalocrinus rugosus, Periechocrinus moniliformis, Actinocrinus pulcher, Cyathocrinus goniodactylus, Pseudocrinites quadrifasciatus.

*Brachiopoda.*—Rhynchonella borealis, Retzia Barrandii, Cyrtia exporrecta, Atrypa reticularis, Pentamerus galeatus, Orthis rustica, Strophomena euglypha, Spirifer plicatellus.

*Lamellibranchs.*—Cardiola interrupta, Grammysia cingulata, Pterinæa asperula, Pt. retroflexa.

*Gasteropoda, &c.*—Euomphalus discors, Eu. funatus, Acroculia haliotis; Conularia Sowerbyi (from Bala); Bellerophon expansus.

*Cephalopoda.*—Phragmoceras ventricosum, Orthoceras primævum, O. annulatum, Gomphoceras pyriforme.

## Fossils of the Clunian (Ludlow).

*Rhabdophora.*—None yet found,

*Actinozoa.*—None specially characteristic.

*Crustacea.*—Homalonotus Knightii, Pterygotus problematicus, Eurypterus abbreviatus, Hemiaspis limuloides.

*Echinodermata.*—Ichthyocrinus pyriformis (and Wenlock), Palæaster Ruthveni, Palæocoma Colvini, Protaster Miltoni.

*Brachiopoda.*—Discina rugata, Lingula cornea, Orthis lunata, Pentamerus Knightii, Chonetes lata.

*Lamellibranchs.*—Avicula Danbyi, Cardiola striata, Grammysia triangulata.

*Gasteropoda.*—Cyclonema corallii, Holopella obsoleta, Pleurotomaria nudata, Platyschisma helicites.

*Cephalopoda.*—Ascoceras Barrandii, Orthoceras bullatum, O. ludense.

*Pisces.*—Plectrodus mirabilis, Pteraspis truncatus, Onchus Murchisonii.

Professor Lapworth divides the Silurian series into zones by means of the Graptolites, which have a limited range.

Clunian.—No Graptolites yet found.

| | | |
|---|---|---|
| Salopian. | Zone of | Monograptus Nilssoni. |
| | ,, | Monograptus testis. |
| | ,, | Cyrtograptus Linnarssoni. |
| | ,, | Cyrtograptus Murchisoni. |
| Valentian. | ,, | Cyrtograptus Grayæ. |
| | ,, | Monograptus exiguus. |
| | ,, | Rastrites maximus. |
| | ,, | Monograptus spinigerus. |
| | ,, | Monograptus gregarius. |
| | ,, | Diplograptus acuminatus. |

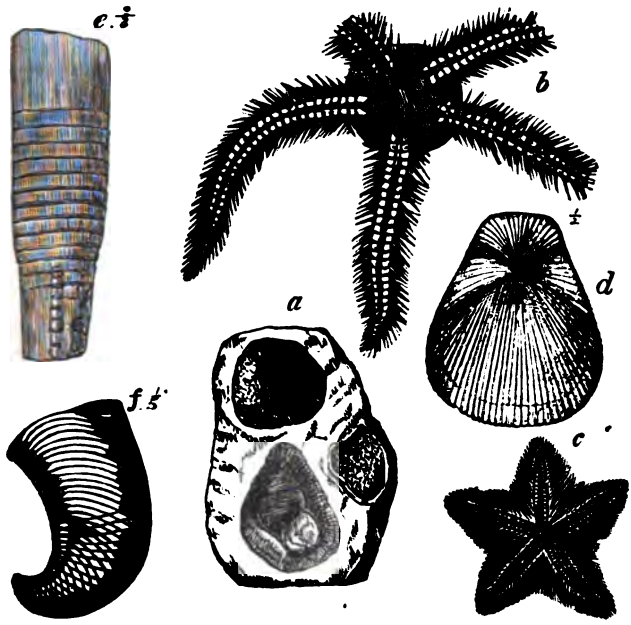



Fig. 18. Ludlow Fossils.

*a*. Cyclonema Corallii.
*b*. Protaster Miltoni.
*c*. Palæocoma Colvini.
*d*. Pentamerus Knightii.
*e*. Orthoceras bullatum.
*f*. Phragmoceras ventricosum.

## *Local Stratigraphy.*

### The Welsh Borders (Shropshire, etc.)

I place the account of these districts first because they include the localities where Silurian rocks were first described by Murchison, Sedgwick, and Phillips, and the sections are therefore classical, though they can hardly be regarded as presenting the normal facies of the Silurian system, for the limestones, which are such prominent members of it in these districts, thin out rapidly when traced westward into Wales, and are there and elsewhere represented by shales and sandstones; they are in fact lenticular masses or episodal beds (see vol. i., p. 310).

In the counties of Gloucester, Hereford, Salop, and Stafford, there are no fewer than nine inlying and isolated areas of Silurian rocks, besides that of Wenlock Edge, which is connected with the main outcrop in Wales. These inlying areas are those of Tortworth, May Hill, Woolhope, Malvern, Abberley, Lickey, Dudley, Sedgley, and Walsall. The same order of succession, more or less complete, is found at all these localities and along Wenlock Edge, so that the following account is applicable to all, and a table of variant thicknesses is appended.

**Valentian.**—The Lower Llandovery sandstone has not been proved to exist in any of these exposures, the basement beds here belonging to the Upper Llandovery group, which everywhere rests unconformably on the older rocks, spreading across the Ordovician beds, and wrapping round the edges of the Longmynd Cambrians. The bottom beds consist of coarse conglomerates, which are 600 feet thick in the Malvern district, and are there overlain by 500 feet of purple sandstone and shale, with a band of impure limestone. Besides the usual fossils, *Lingula crumena* and *Ctenodonta Eastnori* are common near Malvern. At May Hill it consists chiefly of grey and yellowish grits, sandstones, and flagstones. In Shropshire there are coarse grits, with quartz pebbles at the base, overlain by impure limestone with *Pentamerus oblongus*—the Hollies limestone.

The Tarannon shales were found by Mr. W. S. Symonds

in the Malvern tunnel, beneath the Woolhope limestone, and were called by him the "Woolhope shales;" they occur also at May Hill and Woolhope, and are present in Shropshire as purple shales from 200 to 400 feet thick.

**Salopian.**—This series consists of two limestone groups, each overlain by a great thickness of shale.

*Woolhope or Barr Limestone.* At May Hill this consists only of irregular courses and nodules disseminated in shales; at Malvern there are thicker limestones, with shales and sandstones, making up a thickness of 150 feet. In the Woolhope Valley it has a similar composition, and forms a ring round the dome of Llandovery sandstone. It is well exposed at Barr, near Walsall, but below Wenlock Edge it is very thin. The fossils are of the same species as those in Wenlock Limestone above.

Fig. 19. Section from Ledbury to the Malvern Hills, distance about four miles.

| | |
|---|---|
| *j*. Old Red Sandstone. | *e*. Wenlock Shale. |
| *i*. Ledbury Shales. | *d*. Woolhope Limestone. |
| *h*. Aymestry Limestone. | *c*. Valentian. |
| *g*. Lower Ludlow Shales. | *b*. Cambrian. |
| *f*. Wenlock Limestone. | *a* and *x*. Schist and Gneiss. |

*The Wenlock Shales* are found in the same localities, and consist of dark grey or black shales, with occasional calcareous concretions; thickness from 600 to 1,400 feet. *Cyrtograptus Murchisoni* is distinctive of the lower part of these beds.

*The Wenlock Limestone* is a grey limestone full of corals and other fossils, from 100 to 300 feet thick. It is sometimes a single massive limestone formation, as along Wenlock and Benthall Edges; sometimes there are interstratified layers of shale dividing the limestone strata into two or three separate sections, as at Dudley and Walsall. Corals, Echinoderms, Trilobites, and Brachiopods abound everywhere in the limestones.

*Lower Ludlow Shales.*—These originally formed part of Murchison's Ludlow group, but are now associated with the Wenlock beds, because they contain many of the same fossils, and cannot be separated from the Wenlock shales when the intermediate limestone is absent. They consist of soft dark grey sandy shale, often showing a tendency to spheroidal structure, and containing numerous calcareous concretions. Their thickness near Wenlock Edge is about 900 feet.

**Clunian.**—This series varies very much even within the typical district of its occurrence, but the following divisions may here be recognized:—

*Leintwardine Flags.*—The shales above mentioned pass into thick earthy flagstones, which are locally called "pendle." They contain large Orthoceratites, Starfish, and Crustacea of the genera *Pterygotus* and *Eurypterus*. These flags, says Murchison,[1] form the support of the Aymestry limestone, from which they are usually separated by soft soapy beds, in parts an imperfect fuller's earth.

*The Aymestry Limestone* is a dark earthy or argillaceous limestone, often becoming nodular and dying away into bands of calcareous nodules, but attaining a maximum of some fifty feet near Aymestry. *Pentamerus Knightii* and *Lingula Lewisii* are the chief fossils.

*The Upper Ludlow Shales* are soft sandy shales or mudstones, with thin beds of shelly limestone. In Shropshire they are said to be 900 feet thick, but at Malvern they are only about 140 feet. They contain large Eurypterid Crustacea, and are surmounted by a thin layer termed the "Bone Bed," three or four inches thick, but remarkable for containing the earliest remains of Fish, and also for its uniform extension over a considerable area; it has been traced from Ludlow in Shropshire to Pyrton Passage near the mouth of the Severn, a distance of forty-five miles. It may be regarded either as the top of the Ludlow shales, or as the base of the succeeding sandstone.

*The Downton Sandstone.*—A fine yellow thin-bedded micaceous sandstone, quarried for building stone at Downton Castle near Ludlow; its thickness here and at Malvern is about 100 feet.

[1] "Sil.," p. 125.

*Ledbury Shales.*—Red and grey shales and flagstones, which pass upwards into the wholly red beds of the so-called Old Red Sandstone. These and the Downton Sandstone were termed the *Tilestones* by Murchison, and referred to the Old Red Sandstone, but the fossils contained in the grey beds are Silurian forms, and must therefore be included in the older system. Some of the beds are used for tiles, whence the local name. The shales contain *Lingula cornea, Discina rugata, Orthis lunata, Platyschisma helicites,* and species of *Eurypterus* and *Cephalaspis.*

The following table shows the thickness in feet of the several subdivisions at the principal localities above mentioned:—

| | Tortworth. | May Hill. | Woolhope. | Malvern and Abberley. | Staffordshire. | Wenlock. | Aymestry and Ludlow. |
|---|---|---|---|---|---|---|---|
| Upper Ludlow shale | 80 | 170 | 170 | 200 | — | 900 | 900 |
| Aymestry limestone | absent | 50 | 80 | 40 | 25 | 150 | 100 |
| Lower Ludlow beds | absent | 140 | 660 | 700 | 800 | 900 | 900 |
| Wenlock limestone | 100? | 340 | 150 | 280 | 160 | 150 | 100 |
| Wenlock shale | not seen. | 1,000 | 1,000 | 640 | 600 | 1,400 | 1,000 |
| Woolhope limestone | not seen. | 20 | 120 | 150 | 40? | thin | 40? |
| Tarannon shale | not seen. | 440 | 270 | 100 | | 200 | |
| Llandovery beds | not seen. | 440 | 270 | 1,000 | | thin | |

The most noteworthy point which this table brings out is the southerly attenuation of the Ludlow beds lying above the Wenlock limestone; from a thickness of nearly 2,000 feet in Shropshire, these beds are reduced to 360 feet at May Hill, and 80 feet at Tortworth.

### South and Central Wales.

The subdivisions which have been established in the limited area where the Silurian rocks were first described will not apply to the Silurian series outside that area. When traced in any westward direction, a similar change takes place in the lithological character of the rocks: all the limestones thin out and disappear, and the soft mudstones change into a series of hard shales and flags, with

courses of hard grit and sandstone; consequently it becomes difficult to indicate the limits even of the three larger groups into which the system is divided. This, however, has been done approximately, and will eventually, no doubt, be determined in a more satisfactory manner when the Graptolitic zones are worked out.

**Valentian.**—Messrs. Marr and Roberts describe a series of Lower Llandovery beds in Pembrokeshire, consisting of green grits and gritty shales with calcareous bands, containing *Nidulites favus*, *Stricklandinia lirata*, *Phacops elegans*, and *Deiphon Forbesi*. These grits seem to form a continuous strip above the Bala rocks through Caermarthenshire to the neighbourhood of Llandovery, where they have a thickness of about 1,000 feet, and are overlain by coarse sandstones, with layers of *Pentamerus oblongus* (300 feet); these latter are the equivalent of the May Hill Sandstone, and are succeeded by 600 feet of pale blue, green, and brown shales (Tarannon Shale).

A similar succession is found to the west of Builth for a space, but elsewhere the Upper Llandovery is absent, perhaps overlapped by the Tarannon Shale, which, with the Lower Llandovery grits, is found everywhere at the base of the Silurian system through Radnor and Montgomery. They occur also near Presteign, where the sandstone is locally termed "Corton Grit," and the shale is overlain by Woolhope limestone.

Valentian rocks also occupy an extensive area in Cardigan and West Montgomery, where the Bala Beds dip everywhere beneath a central mass of shales and grits which have lately been proved to be Valentian. Jukes long ago remarked[1] "that this group of rocks probably has in reality a much wider extension than has yet been assigned to it, and occupies more or less of the large tract of (so-called) Lower Silurian ground, which spreads in numerous undulations through Cardiganshire and the adjacent counties." This area has recently been examined by Mr. W. Keeping, who makes two groups—the Aberystwith Grits and the Metalliferous Slates, their united thickness being 3,000 feet. The slates contain *Rastrites pere-*

[1] "Manual of Geology," second edition, 1862, p. 452.

*grinus, R. maximus, Monograptus Sedgwickii, M. gregarius,* and many other graptolites; the grits have *Monograptus Sedgwickii, M. turriculatus, Dictyonema delicatulum,* and *Phacops elegans.*

**Salopian and Clunian.**—These come in to the south of Llandeilo, and stretch to the north-east, in a constantly widening strip; but owing to the entire absence of limestones the two groups have not been definitely separated. Near Llandovery they consist of grey shales and calcareous bands with thin sandstones, passing up into a series of thick sandstones with beds of shale, the whole series being 5,500 feet thick, overlain by 800 feet of fossiliferous laminated sandstones or tilestones.

Professor Lapworth remarks that the lower part of the so-called Wenlock series from Llangaddock to Bala Lake is everywhere marked by a zone of dark shale, with *Cyrtograptus Murchisoni.* West of Newtown this shale is about 150 feet thick (Geol. Survey Sections, sh. 30).

At Builth the limestones begin to make their appearance, and the Wenlock shales overlap the Valentian, so as to rest on Llandeilo beds. The succession is as follows, according to De la Beche:—

| | | Feet. |
|---|---|---|
| Clunian. | Micaceous sandstone with fossils (Tilestones) | — |
| | Grey thin-bedded sandstones, often micaceous | 3,168 |
| | Thin band of limestone, with *Pentam. Knightii* | — |
| | Argillaceous sandstones | 210 |
| Salopian. | Thin limestone beds | 10 |
| | Argillaceous sandstones | 300 |
| | Nodules and interrupted beds of limestone (Wenlock fossils) | 10 |
| | Shales with nodules of argillaceous limestone | 550 |
| | Argillaceous sandstones (? representing Denbigh grits) | 250 |
| | Shales with nodules and beds of limestone (?Woolhope) | 750 |
| | | 5,248 |

In the Radnor and Clun Forest area the Wenlock and Ludlow series appear to attain a great development, and consist of the following members in descending order:—

| | | Feet. |
|---|---|---|
| Clunian. | Red marls and grey micaceous sandstones | 1,500 |
| | Sandy and flaggy brown shales, with beds of dark brown sandstone, about | 3,000 |
| Salopian. | Grey and blue sandy shale, about | 1,500 |
| | Thick grey gritty sandstones, with bands of hard slaty shale (Denbigh Grits) | 900 |
| | Black shales with Graptolites | 150 |
| | | 7,050 |

These details are taken from sheet 30 of the Horizontal Sections of the Geological Survey, the thicknesses of the central beds being corrected in accordance with Sir A. Ramsay's estimate.[1]

The Denbigh grits, which replace the lower part of the Wenlock shale, appear to commence near Builth, and thicken rapidly as they are traced to the north-west.

Two inlying areas occur to the eastward of the main outcrop. Near Cardiff the Silurian rocks are brought up by an anticlinal fold, and have been described by Professor W. J. Sollas.[2] They belong to the Salopian and Clunian series, and may be summarized as follows:—

| | | Feet. |
|---|---|---|
| Ludlow. | Grit bed with fish remains | — |
| | Upper Ludlow (grey mudstones) | 254 |
| | Lower Ludlow shales and mudstones | 130 |
| Wenlock. | Thin limestones with shales and sandstones and Wenlock fossils | 74 |
| | Shales and sandstones | 107 |
| | Rhymney grit (sandstones) | 50 |
| | Greenish grey mudstones and sandstones | 380 |

Another Silurian tract occurs to the north-east, between Usk and Pontypool; but here the limestones are well

[1] In this section the Ludlow Beds are drawn as 6,000 feet thick and the Wenlock Shale as 4,000 feet, but in sheet 27 across Radnor Forest the thicknesses are respectively 4,000 and 2,200, and a third section (sheet 6) across the country between Radnor Forest and Builth gives 2,700 (Ludlow) and 2,400 (Wenlock); while Sir A. Ramsay, in his "Memoir on North Wales" (p. 306), states that the average thickness is that given above, viz. 3,000 and 1,500. These discrepancies are possibly due to the existence of concealed flexures which are not shown in the sections.

[2] "Quart. Journ. Geol. Soc.," vol. xxxv., p. 475.

developed, and in all respects similar to those of Woolhope and Malvern. The succession is:—

| | | Feet. |
|---|---|---|
| Ludlow. | Upper Ludlow | 120 |
| | Aymestry limestone | 20 |
| | Lower Ludlow | 190 |
| Wenlock. | Wenlock limestone | 120 |
| | Wenlock shales | 300 |
| | Woolhope limestone | 130 |

### North Wales.

**Valentian.**—In the Hirnant Valley the Hirnant limestone is succeeded by coarse unfossiliferous grits, 250 feet thick, which are now regarded as Lower Llandovery. Similar grits, 50 feet thick, occur in the Corwen Valley, and have yielded *Meristella crassa*. They are absent at and south of Conway, but set in to the east of Bala Lake, and can be followed for about twenty miles to the Tarannon Valley, where they either thin out or are overlapped by the succeeding shales.

No shell-bearing Upper Llandovery has yet been identified, but the Tarannon Shales, with some underlying grits, are everywhere found; the lowest zone consists of black shales, with *Monograptus convolutus*, *M. tenuis*, and *M. gregarius*; and above these are pale green shales, with *Monograptus priodon* and *M. exiguus*. Their thickness is from 600 to 700 feet, and they appear to pass transgressively across the edges of the older beds, for near Conway they rest on beds which are not much higher than the Bala limestone (Ramsay).

**Salopian.**—All along the main outcrop between Conway and Builth, the Valentian shales are succeeded by a series of coarse grits, which are in some places 3,000 feet thick; but along the north side of the Berwyns these thin away, and are replaced by ordinary Wenlock shale. In the centre of Denbighshire the following succession can be made out in descending order: [1]—

[1] See Marr, in "Quart. Journ. Geol. Soc.," vol. xxxvi., p. 277.

4. Coarse grits (seen only in the Clwyd valley).
3. Llansannan shales, with *Atrypa reticularis, Rhynchonella Wilsoni, Rh. nucula, Cardiola interrupta.*
2. Coarse grits, *Calymene Blumenbachii, Phacops caudatus, Orthis biloba, Spirifera plicatella.*
1. Blue flaggy slates, *Cyrtograptus Murchisoni, Monograptus priodon, M. vomerinus, Cardiola interrupta.*

No. 1 clearly represents the lower part of the Wenlock shales, and the remaining stages must be the equivalents of the upper shales and Wenlock limestone.

**Clunian.**—The Silurian series of North Wales ends abruptly with No. 4 of the above, which is succeeded unconformably by the basement Carboniferous conglomerates, and no true Clunian beds are seen. Fragments of the micaceous Tilestones have, however, been discovered in this conglomerate, proving that these uppermost Silurian rocks were originally present, but were destroyed during the Carboniferous subsidence.

## Lake District.

In Westmoreland there is a great thickness of slates, grits, and flagstones, which were first examined and described by Professor Sedgwick; he recognized them as Silurian, and divided them into three sections under the names of, 1, Coniston Grits; 2, Ireleth Slates; 3, Kendal group. The two latter groups have since received different names, and minor subdivisions have been established. The following is the present classification:—

**Valentian.**—Here, as in North Wales, this series consists of three stages; (i.) a set of grits and conglomeratic beds resting unconformably upon the Ordovician series; (ii.) black shales with Graptolites; (iii.) pale green and purple shales. The whole series is not more than 250 feet thick; the two lower groups are termed the Stockdale Shales in the publications of the Geological Survey, and the upper group are called the Pale Slates.

No. i. contains *Favosites fibrons, Meristella crassa,* and several species of *Orthis,* and is evidently the representative of the shell-bearing grits of North Wales. In the

country about Kendal and Sedbergh this stage is absent, and the black shales rest upon the Coniston Limestone.

No. ii. were termed the Coniston Mudstones by Harkness and Nicholson. They contain *Monograptus tenuis*, *M. Sedgwickii*, *Rastrites peregrinus*, and other Graptolites, *Acidaspis granulatus*, *Cheirurus bimucronatus*, and other Crustacea.

No. iii., the Pale Slates, are clearly the equivalent of the Tarannon Shales, but the only fossils found are *Monograptus Becki*, *M. turriculatus*, and *M. priodon*.

**Salopian.**—A series of flags and grits exactly like the Denbigh Flags of Wales, and divisible into the following stages: [1]—

i. Brathay Flags, about 500 feet thick, and containing *Monograptus priodon*, *M. vomerinus*, and *Cyrtograptus Murchisoni*. This is clearly the Cyrtograptus zone which occurs throughout Wales above the Tarannon Shale (see p. 123).

ii. The Coldwell Beds.—Gritty flags and bluish sandy mudstones, containing *Monograptus colonus*, *Phacops Stokesii*, *P. obtusicaudata*, *Actinocrinus pulcher*, *Cardiola interrupta*, and *Orthoceras primævum*. Equivalent to the lower grits and Llansannan Shales of Wales; thickness about 2,000 feet.

iii. The Coniston Grits.—These represent the upper grits of Wales, and are about 4,000 feet thick. *Cardiola interrupta*, *Pterinæa tenuistriata*, and *Orthoceras subundulatum* are the commonest fossils; but near Sedbergh there is a band of coarse grit, about 1,200 feet from the base, which contains a peculiar assemblage, including *Rhynchonella navicula*, *Chonetes lata*, and *Orthis lunata*, these being Ludlow species, and reappearing later on in the higher beds of the same area.

iv. Bannisdale Slates.—These are included in the Salopian series, as they appear to be the equivalents of the Lower Ludlow shales. They are described as sandy mudstones with thin beds of hard sandstone, the whole about 4,000 feet thick. Fossils are rare, but *Orthoceras primæ-*

[1] According to Mr. J. E. Marr, "Quart. Journ. Geol. Soc.," vol. xxiv., p. 871.

*vum, O. subundulatum*, and a variety of *Calymene Blumenbachii* have been found.

**Clunian.**—Above the last come bluish thin-bedded sandstones with subordinate beds of shale, containing *Protaster Miltoni, Rhynchonella navicula, Cucullella Cawdori, Phacops Downingiæ*, and other fossils. There is also a calcareous band which contains *Palæaster* and *Proëtus latifrons*, and has been identified by Mr. Aveline with the Aymestry Limestone.

These beds are about 1,200 feet thick, and above them are massive greenish and grey sandstones, with calcareous (fossiliferous) bands, and passing up into flags resembling the Tilestones. These are known as the Kirkby Moor Flags, and are more than 2,000 feet in thickness. Fossils are abundant, the following being some of the most characteristic:—

| | |
|---|---|
| Lingula cornea. | Grammysia cingulata. |
| Discina rugata. | Cyclonema Corallii. |
| Spirifera elevata. | Holopella gregaria. |
| Chonetes lata. | Orthoceras ludense. |
| Orthonota amygdalina. | Lituites ibex. |

### South Scotland.

The only districts which have yet been studied in detail are those of Girvan and Moffat, and the following account of them is taken from Professor Lapworth's papers.[1]

**Valentian.**—At Quarrel Hill, near Girvan, the base of the Silurian is a conglomerate consisting of large pebbles in a sandy matrix of a dull purplish tint, and overlain by dark grey sandstones (Mulloch Hill) with *Meristella angustifrons, Atrypa hemispherica*, &c. These pass up into graptolitic mudstones, the whole group being 350 feet thick, probably representative of the Lower Llandovery of Wales. The Upper Llandovery is here represented by grits and flags, succeeded by shales with *Monograptus gregarius* and *Rastrites peregrinus*.

[1] "Quart. Journ. Geol. Soc.," vol. xxxiv., p. 240, and vol. xxxviii., p. 538.

In another locality the Mulloch Hill Beds are absent, and the upper beds commence with a conglomerate covered by an impure limestone with *Pentamerus lens* and *P. oblongus*, and succeeded by shales and grits. Above these is the Camregan group, including a limestone still with Valentian fossils. The united thickness of this group is 700 feet. It is succeeded by a series of purple shales and green or grey grits (Penkill group), representing the Tarannon shales, and containing *Monograptus priodon*, *M. exiguus*, and *Cyrtograptus Grayæ*; thickness about 1,000 feet.

In Dumfries the lower half of the above series is represented by a group of soft black shales no thicker than 140 feet, but containing the same Graptolites, and divisible by them into the following zones, in descending order:—

Zone of Rastrites maximus.
" Monograptus spinigerus.
" Diplograptus cometa.
" Monograptus gregarius.
" Diplograptus vesiculosus.
" Diplograptus acuminatus.

The **Moffat Shales** are succeeded by the Gala Beds, a thick series of flagstones and shales, with *Monograptus priodon*, *M. Sedgwickii*, and *Cyrtograptus Grayæ*, and therefore generally equivalent to the Penkill group.

**Salopian.**—In the Girvan area the Penkill beds are followed by the Bargany group, pale flagstones, shales, and mudstones, and these by the Straiton group, consisting of grey flags and shales in the lower part, overlain by grits and conglomerates. These two groups are 1,600 feet thick, and are probably to be correlated with the Coldwell Beds of the Lake District. *Monograptus vomerinus*, *Retiolites Geinitzianus*, *Cardiola fibrosa*, *Beyrichia Klædeni*, and other fossils occur. The Riccarton beds of the Southern Uplands and Mosspaul on the Scotch Border are part of the same Silurian series, and are certainly of Wenlock Shale age.

**Clunian.**—No higher beds have yet been found in the extreme south of Scotland, but near Lesmahago in Lanark the Lower Old Red Sandstone passes down into a thick

series of brown shales and olive-coloured mudstones, exactly like the Upper Ludlow beds of Shropshire, and containing *Orthonota amygdalina*, *Platyschisma helicites*, *Ceratiocaris papilio*, and species of *Eurypterus*, *Pterygotus*, and *Slimonia*. Again, in the Pentland Hills shelly sandstones, flags, and shales occur, which are crowded with fossils of Wenlock and Ludlow species, and these likewise pass up into the Lower Old Red (see fig. 27, p. 151).

### Western Ireland.

The Irish Silurians have not yet been completely worked out and compared with their English equivalents; but representatives of the whole Silurian series appear to exist, those in the west being shore deposits, and those in the east being similar to the deeper water beds of the Lake District.

**Valentian.**—It has already been mentioned that a band of metamorphosed Cambrian rocks ranges through the north of Ireland south-westwards to the shores of Galway Bay. These rocks are unconformably overlaid by conglomerates, sandstones, and shales of Llandovery age, containing pebbles of the Cambrian rocks upon which they rest.[1] The strata are well exposed near Killary Harbour, and along the west side of Lough Mask in Galway, and contain *Atrypa hemispherica*, *Encrinurus punctatus*, *Illænus Bowmanni*, *Trochus multitorquatus*.

Again, at Smerwick Bay (county Kerry) a thick series of red, green, and yellow sandstones, with bands of conglomerate, underlie rocks containing Wenlock fossils; they may, therefore, be referred to the Valentian or Llandovery group, though no fossils have yet been found in them, and their base is not seen. In similar beds at Bulls Head and Caherconree, *Atrypa hemispherica* and other fossils have been found.

**Salopian.**—At Lough Mask the Llandovery beds are overlaid by shales and sandstones containing Wenlock fossils, and interstratified with these are sheets of lava

[1] See Professor Hull's "Physical Geology of Ireland," p. 22.

(eurite) and beds of tuff proving that volcanic outbursts took place in this area of deposition. These beds are 2,400 feet thick, and are still thicker to the west, where they form the Mweelrea mountains, and with the volcanic rocks at the base have a thickness of 3,200 feet. In the Dingle promontory the Smerwick beds are succeeded by the Ferriters Cove beds, which consist of green sands and shales with bands of red sandstone, 2,500 feet in all. In these fossils of Wenlock type occur.

**Clunian.**—Succeeding the last in the Dingle promontory are the Croaghmarhin beds—hard brown calcareous grits with *Pentamerus Knightii* and other Ludlow fossils. These dip southward at a high angle, under a great series of green and purple grits and shales without fossils, which pass up into thick bedded grits and sandstones of red and green tints; these are the Dingle beds or Glengariff grits of Jukes and Du Noyer, who estimate their thickness as from 7,000 to 10,000 feet. They are unconformably overlaid by the Lower Carboniferous sandstones (Old Red Sandstone). See fig. 28.

In Galway the Mweelrea series is overlain by the Salrock beds—red shales with green and red grits, some of which are full of minute *Lingulæ* (*L. Symondsii*), with *Pterinæa retroflexa* and *Trochus multitorquatus*, but no characteristic Ludlow fossils, though they are supposed to be of that age.

### Eastern Ireland.

**Valentian.**—In county Down there appears to be a complete series of Lower Silurian and Valentian beds exposed along the shores of Belfast Lough. They have been studied by Mr. Swanston,[1] who collected the following Graptolites (among many others) from the beds in Coal-pit Bay, which succeed those containing Hartfell species: *Rastrites peregrinus, Monograptus gregarius, M. Sedgwickii, M. tenuis, Diplograptus folium, Retiolites perlatus.* Higher beds representing the Gala and Tarannon groups occur on

[1] "Trans. Belfast Nat. Hist. Field Club," Appendix, 1876-77.

Strangford Lough, and contain many *Monograpti—priodon, turriculatus, riccartonensis*, &c.

At Portraine, co. Dublin, the Coniston limestone is succeeded by dark shales, like the Graptolitic mudstones of the Lake District, overlain by greenish shales comparable to the Stockdale and Knock beds, according to Messrs. Harkness and Nicholson. A similar succession occurs at the Chair of Kildare.

**Salopian.**—The pale shales near Portraine are succeeded by hard grey sandy rocks, resembling the Coniston Flags, but no higher beds have yet been discovered in this part of Ireland.

### *Volcanic Rocks.*

The only part of the British Islands where volcanic rocks are interbedded with Silurian strata is the west of Ireland. The volcanic zone here appears to be at the base of the Wenlock series; at Carhoo, on the west coast of the Dingle promontory, thick beds of volcanic ash and felsitic lava occur with bands of slate containing Wenlock fossils. Again, in the Killary district (Galway and Mayo) there are similar beds at the base of the Mweelrea series, consisting of massive felspathic lavas with thick beds of tuff and agglomerate, the whole group attaining a thickness of 1,200 feet below Mweelrea.

### *European Rocks.*

The most complete series of Silurian rocks on the continent are found in Scandinavia and Bohemia.

SCANDINAVIA.—The Silurian series of Scandinavia has been compared with those of Britain by Mr. J. E. Marr, and the following account is taken chiefly from his description. The principal districts in which the rocks occur are Christiania, Scania, Dalecarlia, Westrogothia, and Ostrogothia. It may be mentioned that the total thickness of the series in Scania (some 5,000 feet) is much greater than the Scandinavian Silurians were formerly credited with. In the other districts it is less than 1,000.

**Valentian.**—In Sweden the Lower Brachiopod schists are succeeded by calcareous sandstones and limestones containing numerous fossils, and these pass up into the "Rastrites schists," the Graptolites of which identify them with the Birkhill shales of Scotland, the zones occurring in the same sequence. Mr. Marr points out that in Dalecarlia the calcareous beds rest immediately upon the Trinucleus shales (of Bala age), and that near Christiania these beds are represented by coarse calcareous conglomerates which rest upon the Chasmops limestone. These facts appear to indicate that a break or unconformity occurs locally at the base of the Silurian series in Scandinavia as in Britain, although in most localities there is apparently an unbroken succession.

**Salopian.**—In Scania, Dalecarlia, and Westrogothia the Rastrites schists are succeeded by the Cyrtograptus schists (= Brathay Flags of Cumberland). They are succeeded in Scania by the Cardiola schists, consisting of shales and interstratified limestones, which are more than 3,000 feet thick, and may be correlated with the Coldwell Beds of the Lake District. The Gothland limestone, which closely resembles the Wenlock limestone in appearance and in its fossil contents, seems to be the sole representative of the Salopian group in that region.

**Clunian.**—A limestone and shale series in Scania has been correlated with the Aymestry limestone by Dr. Tullberg, but Mr. Marr considers it more probably of Salopian age. The sandstones of Kaerrstorp and Æved, however, are certainly of Clunian age, and are respectively 800 and 600 feet thick.

BOHEMIA.—Our knowledge of this area is due to the laborious researches of Barrande, and the divisions established by the great Bohemian geologist have recently been compared with the British groups by Mr. Marr, to whose papers the reader is referred.[1] Their united thickness is between 2,000 and 3,000 feet.

RUSSIA.—In the Baltic provinces the Silurian system is reduced to a thickness of less than 200 feet, but all three

[1] "Quart. Journ. Geol. Soc.," vol. xxxvi. p. 591, and "Classification of Camb. and Sil. Rocks," 1883 (Bell and Sons).

series—Valentian, Salopian, and Clunian—are represented. The beds consist of soft unaltered horizontal strata, the general aspect of which is like that of our Secondary rocks.

### *Physical Geography.*

We have seen that the Ordovician period was one of general depression, but that at its close there was a general upheaval, bringing up portions of the sea-bottom, apparently in the shape of ridges, which formed more or less continuous tracts with some associated islands. This upheaval was of course a gradual movement commencing in some areas during the formation of the Lower Llandovery beds, and continuing until some of these island tracts were of considerable size. The unconformity between the Silurian and Cambrian systems is due to this upheaval.

In Wales there seem to have been several islands in existence during the interval between these periods: one occupied part of South Wales; another included Anglesey and Carnarvon; the tract now known as the Longmynd was the central part of another island, while to the south there was a long island, of which the Malvern Hills formed the central ridge. Land also existed over the east of Ireland, and may have become connected with the Welsh lands, so as to form a large land area over St. George's Channel and the east of Ireland. It is difficult to say whether the Cumberland and Dumfriesshire area was elevated into land at this time, or whether it was continuously covered by a shallow sea; the occurrence of Valentian conglomerates in some localities seems to indicate the presence of islands, but the succeeding graptolitic shales demonstrate that they were quickly submerged by the ensuing movement of depression. The conglomerates are markedly developed in the basement beds of Ayrshire, where they are interstratified with beds of the Birkhill shale type, and indicate seas of some depth, but still in proximity to land, together with strong and varying currents, such as would be developed by tidal action among an archipelago of islands.

The largest land area of this epoch seems to have been on the north and north-west of the British Islands, and its southern border ran in a south-westerly direction through the centre of Scotland and the north of Ireland, and thence sending a broad promontory southwards over the east of Ireland as above mentioned. North of this line there seems to have been a continuous tract of land, though we have no means of knowing how far it extended into the northern seas.

There may also have been some considerable tracts of land to the south of the British Islands over France and Belgium. The Ordovician of Belgium is succeeded unconformably by the Devonian, except here and there where beds occur which seem to be of Valentian age; they contain *Graptolites priodon*, *Sphærexochus mirus*, &c., but do not attain any great local thickness.

That the greater land area lay, however, to the north-west of our islands is proved by the lithological variations of the Welsh Silurians. It has been stated, p. 118, that the Silurian limestones lie almost entirely to the east of Wales, and that they are replaced by shales and sandstones as the beds are traced either to the south-west or to the north-west. The mechanical deposits, and especially the coarse gritty sandstones, are, however, thickest to the north-west in Montgomery and Denbighshire, indicating that the source of supply was in that direction. From the quantity of felspathic grains that enter into the composition of these Denbigh grits, Sir A. Ramsay infers "that part of the mountain region of North Wales, between Conway and Cader Idris, then formed land (very different from its present form) which in some degree contributed locally to make these strata by the waste of the felspathic lavas and ashes that form such a distinguishing feature of the Lower Silurian rocks. From east to west, and from north to south, the coarser gritty beds gradually disappear the farther we recede from the larger centres of these volcanic rocks."[1]

It seems probable, in fact, that these North Welsh and Lake District rocks were formed in a broad gulf which stretched in a north-westerly direction to the south-west

[1] "Geology of North Wales," second edition, p. 285.

of Scotland, and was bounded on the west by the southward jutting promontory before indicated.

The time of greatest depression appears to have been at and between the epochs of the Wenlock and Aymestry limestones; afterwards the deposits everywhere become more sandy, indicating that upheaval gradually extended the coast-lines and narrowed the areas of deposition.

## CHAPTER V.

### Devonian System.

*General Classification and Subdivisions.*

WE have seen in the last chapter that, where complete sections are found, the Silurian rocks pass upwards into a thick series of red sandstones (England and Scotland), or into an equally long series of grey and purple grits (Ireland). It will be shown in a future chapter that the marine Carboniferous rocks always rest upon a set of red and yellow sandstones, which often repose unconformably upon some of the more ancient Palæozoic strata. The marine fauna of the Silurian dies out at the base of the red sandstones; and when we reach the next marine fauna—that of the Carboniferous system—it is totally different from the preceding, so that a long period of time must have elapsed between the close of the Silurian era and the commencement of the Carboniferous.

The groups known as the Old Red Sandstone in England and Scotland, and the Glengariff grits or Dingle beds in Ireland, are clearly some of the rocks which were formed in this interval; and if these were the only records of this portion of geological time, we might find it convenient to regard the whole of the beds which succeed the Silurian series in conformable sequence as belonging to the Silurian system. This is practically what Professor Hull does in proposing to create a Devono-Silurian system, for though he easily succeeds in showing that these beds are indissolubly linked to the Silurian series, yet this fact is no proof that they do not really belong to a separate system.

Moreover, these are not the only strata which are interposed between the Silurian and Carboniferous systems. In Devonshire, and in many localities in Europe, there is a thick series of rocks, containing a marine fauna, which is

evidently of an intermediate age, and in Germany the stratigraphical proof of their interposition between Silurian and Carboniferous rocks is complete. In accordance with the palæontological principle of classification laid down in Part IV., Chapter IV., it is this marine series which must be taken as the normal type of the intermediate system; and any freshwater deposits which can be shown to be of the same age must be treated as local contemporaneous or homotaxial strata. In America both types of the Devonian system are also present.

I hold, therefore, that the Devonian system was established by Sedgwick and Murchison in 1839 on perfectly scientific grounds, namely, because Mr. Lonsdale's study of the Devonshire fossils led him to the conclusion that they formed an important fauna of a character intermediate between those of the Silurian and Cambrian rocks. The system was divided into Lower, Middle, and Upper divisions, each with a special group of fossils; and, if this succession is correct, there can be no doubt about the existence and integrity of the Devonian system.

The succession has, however, been doubted by Mr. Jukes, partly on stratigraphical and partly on palæontological grounds. His main argument was that the whole of the Upper Devonian could be correlated with the Lower Carboniferous rocks of Ireland, and he endeavoured to show that the Lower and Middle Devonians were only repetitions of the Upper series brought in again by a huge fault along the strike, and he thought that the fossils were not opposed to this view.

Jukes' opinion naturally commanded attention, but the most skilled investigators are sometimes led astray, and although there probably is a fault along the line he indicated, yet it is very doubtful whether it has the effect which he supposed; the palæontological evidence is certainly against this hypothesis, and in favour of the view that the apparent succession is practically a continuous one.

The question, therefore, resolves itself into a difference of opinion as to whether certain beds should be attached to the Devonian or Carboniferous systems—where, in fact, the line of separation should be drawn. Jukes thought the whole of the Upper Devonian might be correlated with

Carboniferous beds, but according to Mr. Hull it is possible to draw a line which will cut off the beds in Devon that are really comparable to the Irish rocks, and yet leave certain sandstones to the Upper Devonian. I adopt this arrangement as the best in the present state of our knowledge; and the following is the apparent succession in Devonshire with the probable equivalents in Belgium :—

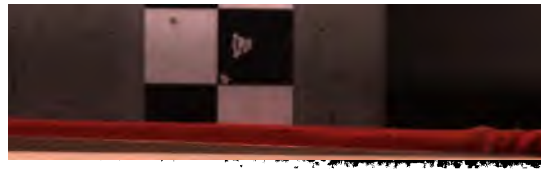
| | N. Devon. | Belgium. |
|---|---|---|
| Upper. | Upcot flagstones<br>Pickwell sandstones | Psammites de Condros and Famennian. |
| Middle. | Mortehoe slates<br>Ilfracombe beds<br>Hangman grits | Frasnian.<br>Givetian and Eifelian. |
| Lower. | Lynton shales<br>Foreland grits | Coblenzian.<br>Gedinnien. |

The Old Red Sandstone, which elsewhere occupies the position of the Devonian system, is believed to be of lacustrine or estuarine origin. It has been divided into a lower and upper series; but there is in Scotland a marked unconformity between them, and it is doubtful whether the upper series is really of Devonian age. It is probable that the Lower Old Red Sandstone may be correlated with the Lower Devonian, that the Middle Devonian was formed during the time represented by the unconformity in Scotland and Ireland, and that only a part of the Upper Old Red Sandstone is really of Devonian age, for deep down in this upper red series of Scotland there is a thin limestone containing typical Carboniferous fossils.

The student will understand that this part of the system requires further investigation, and that our nomenclature stands in need of alteration; the cumbrous designation of Old Red Sandstone should be relinquished, and a new name should be found for the estuarine Devonians, while it must be ascertained how much of the Upper Old Red Sandstone can be correlated with the Upper Devonian of Devon.

### *Surface and Subterranean Extension.*

In Britain the only surface exposures of marine Devonian rocks occur in Devon, Somerset, and Cornwall; they





occupy the northern parts of Devon and Somerset between Morte Bay and the valley of the Tove, as well as the outlying tract of the Quantock Hills, east of that valley. Dipping southward beneath the central Carboniferous area, they reappear in South Devon and North Cornwall.

The strike of these rocks is nearly due east and west, and this appears to be maintained in their subterranean extension through the south of England, for rocks with the same Devonian fossils have been met with in borings beneath the Cretaceous beds which underlie London and Essex. They are known to occur in the same position in Belgium, and they emerge again to the surface in the Ardennes, so there is every probability of their being continous across the intermediate areas.

In crossing the Bristol Channel from North Devon to South Wales we reach an entirely different lithological type, for in Wales the beds between the Silurian and Carboniferous are all of the Old Red Sandstone facies. These rocks occupy a large area between the Silurian tract and the valley of the Severn, and in the south of Brecknock they form a range of lofty hills overlooking the great coal-field of South Wales; they surround the Silurian inliers of Usk and Woolhope, and extend northwards to the neighbourhood of Wenlock in Shropshire.

No more is seen of this Old Red Sandstone till we reach Scotland, where it appears to occupy several distinct basins of deposit: (1) The great central valley, underlying the Carboniferous rocks, and coming to the surface in Ayr, Lanark, and the Pentland Hills on the southern side, and in Dumbarton, Stirling, Perth, and Forfar on the northern side; (2) a smaller area in Berwick, which may or may not have been connected with the first; (3) a small district in the north of Argyleshire; (4) a large basin in the north-east, from Moray Firth to Caithness and the Orkneys.

In Ireland the lower part of the series (Glengariff beds) is again somewhat different; but the upper part is of the Old Red Sandstone type. The Glengariff grits occupy a large area in Kerry and West Cork, forming the greater part of the promontories which separate Dingle, Kenmare, and Bantry Bays. The Fintona beds, supposed to be of same age, form a tract about thirty-five miles long by ten

in breadth, between Lough Erne and Pomeroy in Tyrone. These groups are supposed to represent the Lower Old Red, but the rocks usually called Old Red Sandstone in Ireland form an upper series, and attain their maximum development in Kilkenny, Waterford, and Tipperary.

*Relation to Underlying Rocks.*—Wherever Silurian rocks have been found beneath those of Devonian age, there is a complete passage from one system to the other. In North Devon the base of the Devonian is not seen, and in Cornwall the junction of the two series has not yet been fixed with certainty; but in Wales the Silurians pass up into Old Red Sandstone, and the same is the case in Scotland, though the higher beds extensively overlap the lower. In Ireland there is such complete conformity and lithological similarity between the Silurian and Glengariff beds that in the absence of fossils it is impossible to fix the boundary between them.

### *Life of the Period.*

As already mentioned, the Devonian fauna holds an intermediate place between those of the Silurian and Carboniferous. Most of the specially Silurian genera become extinct in the Lower and Middle Devonian, while in the latter and the Upper Devonian many genera commence which are prominent members of the Carboniferous fauna. This is especially the case with the Brachiopods, for all the Lower Devonian genera are Silurian, while all those in the Upper Devonian range into the Carboniferous.

The Old Red Sandstone is characterized by the first appearance of plants in Britain, and by the abundance of Fish and Eurypterid Crustacea.

The following are the generic characteristics of the period:—

*Plants.*—Psilophyton, Caulopterus, Palæopteris, Sigillaria, Calamites, and Lepidodendron appear.

*Spongida.*—Abundance of Stromatopora.

*Actinozoa.*—Acervularia, Alveolites, Cyathophyllum, Cystiphyllum, Heliolites, and Favosites continue from Silurian; Rhizophyllum (Calceola) and Pleurodictyum are peculiar; Zaphrentoid corals appear for the first time.

*Echinodermata.*—Cyathocrinus and Taxocrinus continue; Cupressocrinus, Hexacrinus, and Melocrinus are peculiar to Devonian; Platycrinus appears and survives.

*Crustacea.*—Trilobites are on the decline; only six genera found in Britain—Bronteus, Cheirurus, Harpes, Homalonotus, Phacops, and Phillipsia; the first four die out. Eurypterus, Pterygotus, and Stylonurus occur.

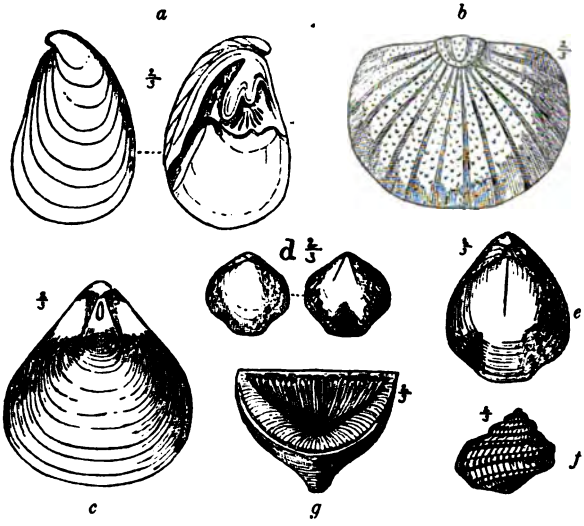



Fig. 20. Middle Devonian Fossils.

*a.* Megalodon cucullatus.
*b.* Bronteus flabellifer.
*c.* Stringocephalus Burtini.
*d.* Meristella plebeia.
*e.* Pentamerus brevirostris.
*f.* Pleurotomaria aspera.
*g.* Calceola sandalina.

*Brachiopoda.*—Many new and peculiar forms—Cyrtina, Camarophoria, Davidsonia, Renseleria, Stringocephalus, Uncites. Productus and Terebratula commence.

*Lamellibranchs.*—Megalodon, Pleurorhyncus, Corbula, and Cleidophorus are new, the last two surviving. Cucullæa, Ctenodonta and Curtonotus are abundant.

*Gasteropoda, &c.*—Loxonema, Macrocheilus, Euomphalus, Pleurotomaria, Murchisonia, Bellerophon, Porcellia.

*Cephalopoda.*—Orthoceras, Cyrtoceras, Phragmoceras continue; Clymenia, Goniatites, Poterioceras, Trochoceras, and Bactrites appear, and Clymenia does not survive.

*Fish.*—Cephalaspis, Pteraspis, Phyllolepis, Diplacanthus, Acanthodes, Osteolepis, Dipterus, Coccosteus, Pterichthys, Glyptopomus, Holoptychius, and Phaneropleuron, are some among many.

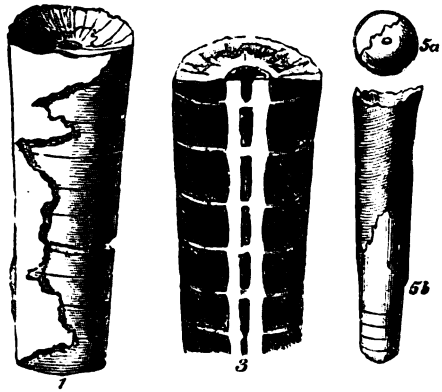



Fig. 21. Devonian and Silurian Orthocerata.

1. Orthoceras striatum (Dev.).
3. Orthoceras, vertical section, showing siphon and chambers.
5. Orthoceras gregarium (Sil.).

The following are some of the species characteristic of each series:—

## Fossils of the Lower Devonian.

*Actinozoa.*—Pleurodictyum problematicum, Cyathophyllum helianthoides.

*Echinoderms.*—Cyathocrinus megastylus, C. pinnatus.

*Crustacea.*—Phacops laciniatus, Homalonotus elongatus.

*Brachiopoda.*—Atrypa reticularis, Orthis arcuata, Spirifera lævicosta, Sp. canalifera.

*Lamellibranchs.*—Ctenodonta Kratchæ.

## Fossils of the Middle Devonian.

*Spongida.*—Stromatopora concentrica, St. placenta.

*Actinozoa.*—Acervularia pentagona, Favosites polymorpha (cervicornis), Cyathophyllum cæspitosum, Cystiphyllum vesiculosum, Calceola sandalina, Heliolites porosa.

*Echinoderms.*—Cyathophyllum geometricus.

*Crustacea.*—Bronteus flabellifer, Harpes macrocephalus.

*Brachiopoda.*—Atrypa desquamata, Stringocephalus Burtini, Pentamerus brevirostris, Meristella plebeia, Uncites gryphus.

*Lamellibranchs.*—Megalodon cucullatus.

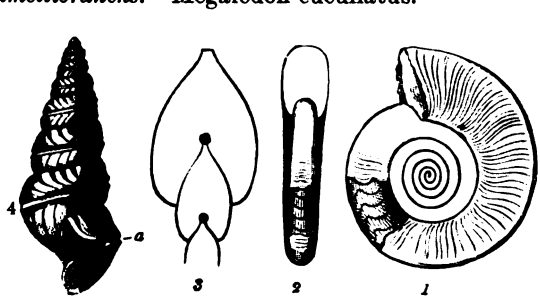



Fig. 22. Devonian Fossils.

1, 2. Clymenia Sedgwickii. 3. Section of Clymenia striata.
4. Murchisonia angulata (Middle Dev., from the Eifel).

*Gasteropoda*, &c.—Macrocheilus brevis, Murchisonia bilineata, Pleurotomaria aspera, Euomphalus serpens, E. annulatus, Porcellia Woodwardii.

*Cephalopoda.*—Cyrtoceras ornatum, C. nodosum.

## Fossils of the Upper Devonian (Petherwin).

*Crustacea.*—Phacops granulatus, Ph. latifrons (also in Mid. Dev.), Cypris (Entomis) serrato-striata.

*Brachiopoda.*—Spirifera Verneuillii, Orthis interlineata, Strophalosia productoides.

*Lamellibranchs.*—Aviculopecten transversus, Cardiola retrostriata (Cardium palmatum).

*Cephalopoda.*—Clymenia lævigata, C. striata, Goniatites linearis, G. subsulcatus, Orthoceras striatulum.

## Fossils of the Lower Old Red Sandstone.

*Plants.*—Psilophyton robustum, Lepidodendron nothum.

*Crustacea.*—Pterygotus Anglicus, Stylonurus Symondsii, Estheria membranacea.

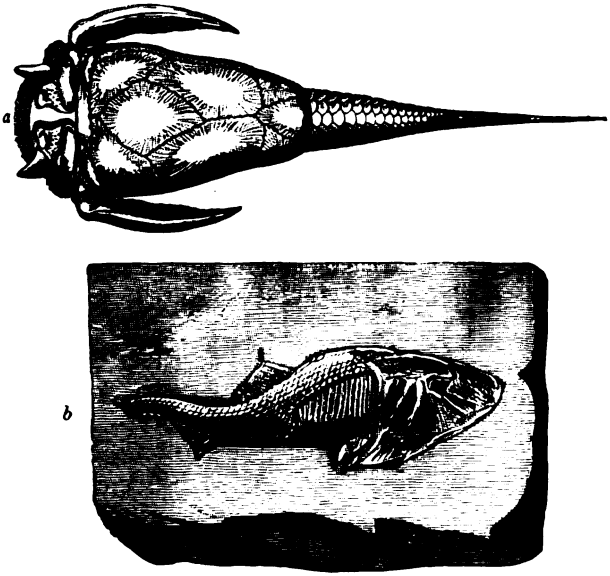



Fig. 23. Devonian Fish.

*a*. Pterichthys cornutus. *b*. Cephalaspis Lyellii.

*Fish.*—Cephalaspis Lyellii, Pteraspis Lloydii, Osteolepis macrolepidotus, Diplacanthus gracilis, Acanthodes Peachii.

## Fossils of the Upper Old Red Sandstone.

*Plants.*—Palæopteris Hibernica, Knorria Bailyana, Cyclostigma Kiltorkense.

*Mollusca.*—Anodon Jukesii.

*Fish.*—Coccosteus decipiens, Holoptychius nobilissimus, Pterichthys major.

### *Stratigraphy.*

### A. Devonian Type.

#### 1. *North Devon and Somerset.*

Fig. 24 is a diagrammatic section across North Devon, showing the apparent relation of the beds and the position of the fault ($t^2$) which was supposed to exist by Jukes; the throw of this as drawn is very small, but he supposed it to repeat the whole series above.

**Lower Series.**—The lowest beds are found at the Foreland, near Lynmouth, and are called the Foreland sandstones. They consist of hard, fine grained, red, brown, and grey grits or sandstones of considerable thickness; they form an anticlinal curve, and rolling over to the south are faulted against the Lynton slates in the valley of the Lynn brook. No fossils have yet been found in them.

The Lynton beds are grey and blue slates and grits, with thin bands of impure limestone, in which many of the characteristic fossils occur (see *ante*), especially Corals and Brachiopods. Their thickness is estimated at 1,200 feet.

**Middle Series.**—The Hangman grits succeed the Lynton group, and consist of red and grey grits, with slates in the lower part, coarse white, red, and speckled grits above. The thickness is about 1,000 feet, and on the coast they extend from Trentishoe to Hangman Hill by Combe Martin Bay, where they are succeeded by the Ilfracombe group. These are silvery slates and sandstones with lenticular bands of limestone in which fossils are numerous; they extend by Ilfracombe to Lee Bay, and may be 4,000 feet thick; but the whole country is so complicated with faults and flexures that any estimate of thickness is necessarily an approximate guess.

Above the last group come the Morte or Mortehoe slates of glossy grey and purple colours, which are generally placed in the Middle Devonian, because they seem to be a natural continuation of the Ilfracombe beds, but no fossils have yet been found in them, though their thickness is estimated at 3,000 or 4,000 feet.

**Upper Series.**—The Pickwell Down beds are described by Mr. Ussher as consisting of purple slates at the base, succeeded by brown and greenish grits, the highest beds being red and grey grits overlain by dull red slates, all without fossils, and 3,000 feet thick. These red and grey beds in the coast section pass up into the green slates of the Baggy series which are now placed in the Carboniferous system; but at Upcot there are yellowish flagstones at or near the top of the Pickwell group, and these contain *Knorria dichotoma* and other plant remains.

### 2. *South Devon and Cornwall.*

The clearest succession in this southern area is found along the south coast of Cornwall, the beds in South Devon being more faulted, contorted, and metamorphosed. Near Torquay and Plymouth, however, the complications have been partially unravelled by Dr. Holl, Mr. Champernowne, and others, and part of the succession is shown in fig. 25.

**Lower Series.**—In Cornwall the lowest beds appear to be the red grits and slates of Polruan, Fowey, and Polperro on the south coast; they contain scales of *Scaphaspis*, *Pteraspis*, and *Phyllolepis concentricus*, fossils which link them to the Lower Old Red Sandstone, but they may be only the lower part of the Middle Devonian.

In the South Devon section (fig. 25) the lower series is brought up by faults about two miles east of the railway at Warberry Hill, and consists of tough grits and sandy slates with *Homalonotus* and *Pleurodictyum*; they are also found at Meadfoot, in Torbay, where scales of *Phyllolepis* occur.

**Middle Series.**—The strata exposed on the West Cornwall coast from Towan Head to Padstow belong to this series, for they include bands of limestone containing *Stringo-*

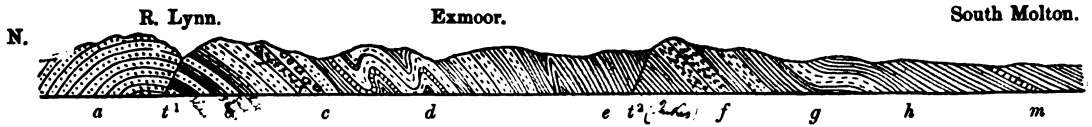



Fig. 24. Diagrammatic Section through North Devon. Distance about 15 miles.

*m*. Culm-Measures
*h*. Pilton Beds
*g*. Baggy Beds
} Carboniferous.

$t^1$, $t^2$. Faults.

*f*. Pickwell Beds.
*e*. Morte Slates.
*d*. Ilfracombe Beds.
*c*. Hangman Grits.
*b*. Lynton Beds.
*a*. Foreland Sandstones.

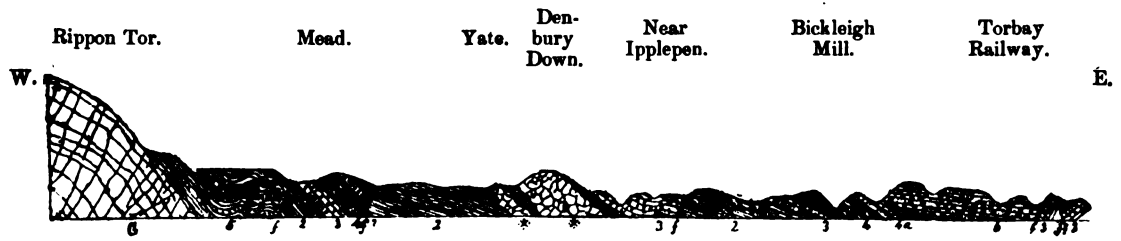



Fig. 25. Section from Dartmoor to near Torquay. Distance about 12 miles.

6. Triassic Sandstones.
5. Culm-Measures.
4*a*. Slates and Red Limestone
4. Slates and Diabase Tuffs
} Up. Devonian.

3. Limestones
2. Green and Purple Slates
} Mid. Devonian.
*g*. Granite.
*f*. Faults. * Volcanic Rocks.

*cephalus Burtini*, *Pentamerus brevirostris*, *Atrypa desquamata*, and other fossils. From the coast they run eastward by Bodmin and Liskeard to Plymouth, and thence to Torbay. Near Plymouth they contain massive limestones, which are largely quarried for building and paving purposes; similar limestones occur near Torquay, some of which yield ornamental marbles, as at Ipplepen, near the line of section, fig. 25. These limestones are rich in Corals —*Heliolites*, *Favosites*, *Acervularia*, and *Cyathophyllum*.

**Upper Series.**—In Cornwall the Tintagel slates are believed to belong to this series—the strike is here north-easterly, but they curve round by Forrabury and strike eastward to South Petherwin. Here the slates contain limestones which yield *Clymeniæ* and other fossils characteristic of the Upper Devonian beds on the continent.

In South Devon a similar series of blue and red slates with a band of limestone occupies a large area between Plymouth Sound and Start Bay. Another small tract of the same beds occurs near Ashburton (see fig. 25), and the Culm series (Carboniferous) is said to be unconformable to them, possibly from a local absence of the Baggy and Pilton groups, for these red slates are probably to be correlated with the upper part of the Pickwell Down series of North Devon.

## B. Old Red Sandstone Type.

### 1. *Wales and Hereford.*

In Hereford and the adjoining counties an immense mass of red rocks, estimated at from 8,000 to 10,000 feet in thickness, intervenes between the Silurian and the Carboniferous. The succession is apparently as continuous as that of the marine Devonians, but fossils of any kind are rarely met with. The following divisions have been made:—

Upper: red sandstones and conglomerates.
Middle: brown sandstones and flagstones.
Lower: red sandstones and marls, with "cornstones."

How much of the upper group is homotaxial with the

Pickwell Down sandstone, and how much with Carboniferous basement beds elsewhere, is quite uncertain; neither has any line yet been fixed between the lower series and the Clunian sandstones.

**Lower Series.**—This is the "Cornstone Series" of some writers, cornstone being the local name for the calcareous concretions or nodular limestones of red and yellow colours which are of frequent occurrence. The lowest beds are red marls and flagstones, with some bands of white sandstone (see fig. 26); the higher beds are red and green marls, with cornstones and sandstones. Fish and Crustacean remains are found in the quarries near Leominster, and also at Putley and Perton, near Woolhope, while near Bedw Llwyd, in Brecon, *Lingulæ* have been found, proving that some of the beds are estuarine, if not marine.

**Middle Series.**—This is a monotonous series of brown and chocolate-coloured sandstones, with some red shales, the whole attaining a great thickness in Hereford and also in Brecon, forming the lower slopes of the Black Mountains and Brecon Vans. A *Eurypterus* and fragments of *Cephalaspis* are the only organic remains yet discovered.

**Upper Series.**—This is a more variable group, but there are always beds of quartz conglomerate in the lower part, with occasionally beds of red marl, and sometimes these are succeeded by red and yellow sandstones. In these sandstones remains of *Holoptychius* and *Pterichthys* have been found, and they pass conformably under the Carboniferous shale.

When traced northward into Shropshire, the Old Red Sandstone thins to about 3,700 feet between Ludlow and the Clee Hills; eastward also a similar thinning takes place, the apparent thickness south of Llandeilo being only 4,000 feet, and the same is the case in Monmouth, but it has been suggested that the upper series overlaps and conceals some of the lower beds.

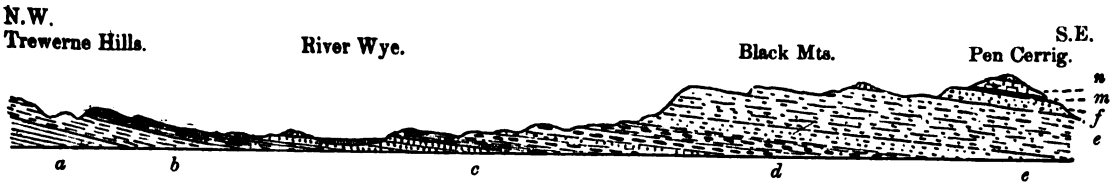



Fig. 26. Section from the Trewerne Hills to the Black Mountains. Distance about 20 miles.

*n*. Carb. Limestone.
*m*. Carb. Shale.
*f*. Red Sandstones.
*e*. Brown Sandstones.
*d*. Cornstone Series.
*c*. Whitish Sandstones.
*b*. Red Marls and Flagstones.
*a*. Ludlow Shales and Tilestones.

Fig. 27. Diagrammatic Section through the Pentland Hills.

*m*. Edge Coals } Carb.
*e*. Basement Sandstones }
*d*. &c., Lower and Upper Divisions of Lower Old Red Sandstone.
*f f*. Faults.
F F. Felstones.
*b*. Ludlow } Silurian.
*a*. Wenlock }

### 2. *Scotland.*

Professor Geikie considers that the four areas of Old Red Sandstone, mentioned on p. 140, were distinct and separate basins of deposit, at any rate during the earlier half of the period; that they were also disconnected from the sea and formed large inland lakes. He has, therefore, proposed separate names for these basins, calling the south-eastern area Lake Cheviot, the central one Lake Caledonia, the small western basin Lake of Lorne, and the northern basin Lake Orcadie. In all there is the same general succession, viz., a great series of red conglomerates and sandstones, which either passes down into the Silurian or rests unconformably on rocks older than the Silurian. In the southern areas this series is covered by another set of red sandstones, some of which may represent the Upper Old Red group, but they pass up into Carboniferous rocks, and they rest with a marked unconformity upon everything below, including the Lower Old Red.

The following is a brief description of the rocks found in each of the three principal basins.

1. **Lake Cheviot.**—In Berwickshire the Lower Old Red forms a band of no great width running from the coast at Eyemouth and Coldingham, along the foot of the Lamberton Hills, till at Auchencraw it is abruptly overlain by the Upper Red Sandstones mentioned below. The older series rests on the upturned edges of the Ordovician rocks, and consists of red felspathic sandstones and marls, with beds of volcanic conglomerate and ash. Fragments of *Pterygotus* and obscure plants are the only fossils yet obtained. Another tract occurs to the south-west in the Cheviot Hills.

It is doubtful whether any of the Upper Red series is really of Devonian age, but the lowermost red beds containing *Palæopteris hibernica* and fish scales were formerly classed by the Geological Survey as Upper Old Red, but are now grouped with the Carboniferous. These form a broad band extending, with some interruptions, from Berwick, by Chirnside and Greenlaw, to Jedburgh and Teviotdale. They rest partly on the Lower Old Red and partly on Ordovician; their basement beds are breccia and

conglomerate, and the higher beds are red sandstone and marl; northward they stretch to the Lammermuir Hills, and in one place they pass over into Haddingtonshire, proving that the two basins were then connected.

2. **Lake Caledonia.**—In this basin the lower series consists chiefly of reddish-brown, grey, and yellow sandstones, with a grey flagstone group in Forfar, the whole attaining a thickness of 20,000 feet.

On the south side of the basin the most complete succession is found near Lesmahago in Lanark, and is as follows:—

4. Purple and chocolate-coloured sandstones, with sheets of felstone.
3. Red sandstones and conglomerates.
2. Red shales.
1. Dark shales and flags, with *Pterygotus* (Silurian).

In the Pentland Hills the lowest part of the same succession is again found, but the uppermost beds (4) are here unconformable to those below; they were formerly classed as Upper Old Red, but when the mapping of Lanarkshire was completed by the Scotch Geological Survey they were found to be continuous with the upper part of the Lower Series, the unconformity being a local phenomenon.[1] This upper group in the Pentland Hills comprises a great thickness of red, green, and yellow rocks, conglomerates, grits, and sandstones, with interbedded sheets of felsite and porphyrite; the sedimentary beds alone amounting to some 3,000 feet, while the volcanic rocks are probably of equal thickness (see p. 160). The highest sheet of felsite is at Liberton covered unconformably by a coarse conglomerate, consisting mainly of well-rounded pebbles of felsite embedded in a felspathic or occasionally a calcareous paste; and this bed is now taken by the Survey as the base of the Carboniferous series. Above it are red sandstones and marls.

In Perth, Fife, and Forfar, along the northern lip of the great trough or basin, complete sections of the Old Red

[1] See Explanation of Sh. 24, Scotland, Mem. Geol. Survey.

Sandstone are found, and exhibit a somewhat different type, viz.:—

| | |
|---|---|
| Upper. | Yellow sandstones and shales. |
| | Red conglomerates and sandstones. |
| Lower. | Grey flagstones, with green and olive shales, containing *Pterygotus* and fish remains. |
| | Dark shales, with *Pterygotus* (Silurian). |

The flagstones are known as the Arbroath Flags, and in the Sidlaw and Ochil Hills they contain thick interstratified sheets of felspathic lava and ash.

These beds are overlain unconformably by red conglomerate and sandstone, succeeded by pale yellow sandstones and shales, which are well seen at Dura Den, near Cupar, a locality celebrated for the abundance of fish remains.

3. **Lake Orcadie.**—In this northern basin the Old Red Sandstone rests upon the metamorphic rocks of the Highlands; its border skirts the hills along the south side of the Moray Firth, and then bends northward through the east of Ross and Sutherland. It occupies the whole of Caithness, and must have once stretched far into the North Sea, if not entirely across to Scandinavia. The most complete sections are found in Caithness, and show the following series in descending order:—

| | Feet. |
|---|---|
| 4. Red sandstones of Dunnet Head . . | 2,000 |
| 3. Dark grey bituminous flagstones and shales . . . . . | 11,400 |
| 2. Deep red micaceous sandstones and flags | 2,000 |
| 1. Basement conglomerates and sandstones, the former containing large blocks of the rocks on which they rest . . | 800 |
| | 16,200 |

No. 3 is believed to be the equivalent of the Arbroath Flags. Caithness seems to have been the deepest part of the basin; in the Shetland and Orkney Islands there is about 6,000 feet, but along the Moray Firth there is frequently less than 1,000 feet.

The so-called Upper Old Red is found in the Orkneys, at

Tarbet Ness and near Nairn, and consists of red and yellow sandstones, which repose unconformably on the older series.

### 3. *North Ireland.*

In the north of Ireland there are also two distinct kinds of rock which have been classed as Old Red Sandstone.

*Fintona Beds.*—The lower group occupies an area about thirty miles long by ten wide between Lough Erne and Pomeroy in Tyrone. "It consists for the most part of dark red and purple conglomerates, often coarse and massive, and of purple pebbly and fine-grained sandstones, . . . with sandy shales. The pebbles in the conglomerate, which vary from the smallest size up to blocks over a foot in diameter, consist of purple felstone, grits, schist, and quartzite. Of all these the felstone pebbles are by far in greatest proportion,"[1] and have been derived from the breaking up of contemporaneous lava streams, some sheets of which still remain interbedded with the conglomerates. This series is considered to be homotaxial with the Glengariff grits, and with the Lower Old Red of Scotland.

Another tract of similar conglomerate has recently been discovered in Donegal, between Lough Swilly and Mulroy Bay. The pebbles and blocks are all derived from the surrounding metamorphic rocks, and the thickness seen is about 800 feet.

**Upper Series.**—This consists of reddish-brown conglomerates, containing pebbles of white and pink quartz; it rests unconformably on the Tyrone beds, and is overlain by purple, brown, and grey sandstones, with sandy shales. There is much resemblance between these beds and the basal beds of the Upper Old Red Sandstone in Waterford, but it is more probable that they are really Lower Carboniferous; for in Tyrone they are directly succeeded by the Carboniferous Limestone, and though other beds (sandstones and shales) come in between them in Derry, these are marine, representing apparently the Coomhola grits (or Calciferous sandstone), while if the conglome-

[1] J. Nolan in "Quart. Journ. Geol. Soc.," vol. xxxv. p. 529.

rates were really Old Red Sandstone, they would pass up into beds of the freshwater Kiltorcan type, but such beds are not to be found.

### 4. *South Ireland.*

The strata to which the name Old Red Sandstone is usually applied in Ireland are chiefly developed in Waterford and the adjacent counties, but these appear to represent only the upper portion of the Welsh Old Red Sandstone, and they rest unconformably on rocks of Ordovician age. In the west (Cork and Kerry) a thick series of rocks come in above the Silurian which seem to represent the Lower Old Red, but these are succeeded unconformably by the Upper group, and nothing has yet been found which fills this gap and represents the Middle series of Wales. The relations of the western beds are shown in the section, fig. 28.

**Glengariff and Dingle Series.**—In the coast section of the Dingle promontory, the beds with Ludlow fossils are conformably overlain by grey, brown, and purple slates without fossils, followed by alternations of grey grits and slates, the grits at length predominating and forming a thick series of hard massive green and purple grits. The whole of this gritstone series is perhaps 8,000 feet thick, and it is succeeded by slates of red and purple tints, with beds of conglomerate at Parkmore, which curiously enough enclose pebbles containing Silurian fossils. No other fossils have yet been found, and except for the occurrence of these derived pebbles, the whole of these slates and grits might be taken for a continuation of the Silurian rocks, so completely similar are they to the underlying fossiliferous series.[1]

A similar set of green grits, surmounted by purple slates with bands of grit, occupies large areas to the south and south-west of Dingle Bay in the Iveragh and Dunkerron promontories, and in the districts of Killarney,

[1] See Professor Hull's paper, "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 703.

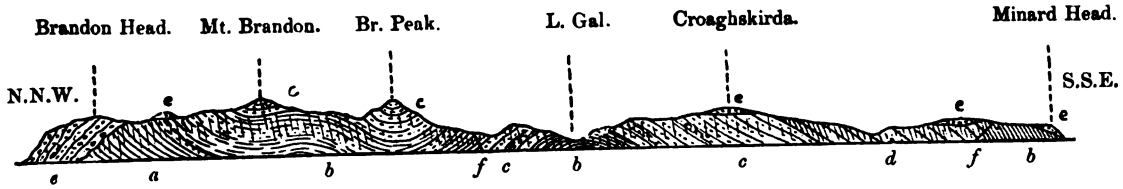



Fig. 28. Section across the Dingle Promontory (after Hull).

*a*. Beds with Silurian Fossils.
*b*. Grits and Slates without Fossils.
*c*. Glengariff Grits.
*d*. Purple Slates.
*e*. Upper Old Red Sandstone.
*f*,*f*. Faults.

Kenmare, and Glengariff. No fossils have been found in these rocks except a few plant remains.

**Upper Old Red Sandstone.**—In the Dingle district the slates above mentioned are abruptly cut off and covered by coarse red conglomerates, which are estimated to have a thickness of 4,000 feet; they overstep the whole Glengariff and Silurian series, and are found again on the northern side of the promontory, resting against the truncated edges of the Wenlock beds (see fig. 28). There is here, therefore, a great gap and unconformity.

About Tralee and Killarney, however, no such conglomerates are found, but beds of brown and yellow sandstone, with red and olive-green shales, are found between the Glengariff slates and the Carboniferous shale. Near Tralee these are 600 feet thick, but near Killarney they are only 150 feet, and when the Carboniferous beds are brought in again along the Sneem and Kenmare trough, neither the conglomerate nor the yellow sandstone group is to be found. At these places the Carboniferous shale or slate is in contact with the Glengariff grits, and though there is no clear proof of any unconformity, yet the beds are thrown into such sharp folds, that it would be difficult to detect any slight discordance, and in view of the clear relations of the two series in the Dingle section, Professor Hull's explanation appears a probable solution of the difficulty. He supposes that the Carboniferous beds gradually overlap the Upper Old Red along a shelving bottom, so that they eventually come to rest on the Glengariff series without the intervention of any red conglomerates or sandstones. Further south, at Glengariff, the yellow sandstones are again found, and *Palæopteris hibernica*, *Sageneria*, and *Anodon Jukesii* have been found in them near Toe Head. It appears, therefore, that a promontory jutted out into the western end of the lake in which the yellow sandstones were deposited, and that the whole area was subsequently and gradually submerged beneath the waters of the Carboniferous sea.

This lake appears to have had a wider and deeper extension to the eastward, for the yellow sandstones may be traced through Kilkenny and Waterford, lower and lower beds coming in till the formation attains the thickness of

TABLE SHOWING THE PROBABLE HOMOTAXIS OF THE DEVONIAN AND OLD RED SANDSTONE GROUPS.

| N. Devon. | Wales. | S. Ireland. | Pentland Region. | Perth and Fife. |
|---|---|---|---|---|
| Marwood Beds and Upcot Flags. | Red and Yellow Flags. | Kiltorcan Flags. | Red Marls and Sandstones. | Dura Den Flags. |
| Pickwell Down Sandstones. | Red Sandstone Series. | Red Sandstone Series. | Liberton Conglomerates. | Red Sandstone Group. |
| Morte, Ilfracombe, and Hangman Beds. | Brown Sandstone Series. | (Absent.) | (Absent.) | (Absent.) |
| Lynton Beds and Foreland Sandstones. | Cornstone Series. | Glengariff Series. | Lower O. R. S. | Lower O. R. S. |

There is a forcible objection to the above correlation, viz., that the Upper Devonian of North Devon is regarded as coeval with the Petherwin Beds on the one hand and with the Lower Carboniferous of Scotland on the other, the former containing marine Devonian species and the latter marine Carboniferous species (in Arran). This point requires further examination; it is just conceivable that a Carboniferous fauna in Scotland may have been contemporaneous with that of the *Clymenia* beds of South Devon, but it is much more probable that the Petherwin fauna preceded that of the Carboniferous limestones and shales.

3,200 feet. Where thus developed, the basement beds are always conglomerates resting unconformably on older rocks, and consisting of quartz, quartzite, jasper, and other pebbles. Near Waterford, for instance, they are conspicuous in the cliffs above the railway station, and lie nearly horizontally on vertical Ordovician slates. Above these conglomerates are dark red brown sandstones, succeeded by grey and purple sandstones with red shales, and finally yellow and greenish sandstones with olive-green shales. These last are known as the Kiltorcan beds, and contain a remarkable assemblage of fossils, including *Anodon Jukesii*, *Palæopteris hibernica*, and other plants, scales of *Coccosteus* and *Glyptolepis*, and fragments of *Eurypterus*, *Pterygotus*, and *Proricaris*. Eastward the sandstones thin out again beneath the Carboniferous Limestone, which finally overlaps them against the granite of Carlow.

### Volcanic Rocks.

**Devon and Cornwall.**—No contemporaneous lavas are found in North Devon, but South Devon was the site of volcanic eruptions, and many sheets of felsite are interstratified with the Middle Devonians in some places.[1] Basic lavas and beds of greenstone tuff also occur near Saltash, and extend eastward into Cornwall.

In Cornwall, Mr. J. A. Phillips[2] has described several tracts of volcanic rocks, those between Camelford and Trevose Head being clearly contemporaneous, and consisting of sheets of compact dolerites, vesicular lavas, and beds of ash, but in many of the dolerites the augite has been partially or wholly converted into hornblende. There are also intrusive dolerites which are probably of Devonian age, because they are displaced by the post-Carboniferous granite bosses.

**The Cheviots.**—In this district thick sheets of andesitic lava and tuff are interstratified with the Lower Old Red Sandstone. Mr. Teall states[3] that these andesites

[1] See Dr. Holl, "Quart. Journ. Geol. Soc.," vol. xxiv. p. 400.
[2] "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 471.
[3] "Geol. Mag.," Dec. 3, vol. ii. p. 116.

fall into three groups, characterized respectively by the minerals hypersthene, augite, and mica. "The presence of tuffs, vesicular lavas, and amygdaloidal varieties of lava and actual evidences of flow, proves that the conditions of eruption were substantially identical with those of modern times." He also describes some bosses of augite-granite which may possibly be the cores of the volcanoes whence the andesitic lavas were ejected. These eruptions were followed at a later period by the intrusion of quartz-felsite dykes, and Mr. Teall makes some suggestive remarks as to the reason of this sequence in the volcanic rocks. Similar rocks are found in the Lower Old Red Sandstone of Roxburgh and Berwick. Near Eyemouth, on the coast, there is a mass of very coarse agglomerate, which suggests the immediate neighbourhood of a volcanic orifice, while northwards and south-westward the stratified ash-beds become finer in texture, and finally, near Auchencraw, pass into felspathic sandstones; the interbedded felstones likewise thin out in the same direction, so it becomes clear that one volcanic vent was situate near Eyemouth.

**The Pentlands.**—Here again volcanic rocks occur in the upper part of the Lower Old Red series, each ridge of the chain being formed by massive sheets of felspathic lava, which are interbedded with thin layers of ash and conglomerate (see fig. 27, p. 151). The lowest felstone is a compact blue rock, becoming porphyritic and amygdaloidal above; the next sheet is of a pale flesh tint; the higher sheets are mostly of pale pink or greyish white colours. They all dip to the south-east, at angles of 25° to 30°.

**Sidlaw and Ochil Hills.**—These hills form a chain between sixty and seventy miles in length, and their features are wholly due to the immense masses of volcanic rock which occur in the Lower Old Red series. Sheets of felsite and porphyrite alternate with beds of tuff and conglomerate, and attain an aggregate thickness of about 6,000 feet. According to Dr. A. Geikie their disposition shows that the volcanic vents were arranged in a line parallel with the general strike of the beds, and with the trend of the ancient shore-line.

**The Shetlands.**—There seem to have been but few contemporaneous volcanoes within the area of Lake Orcadie

except in the Shetlands. Here, as in the Cheviots, the earliest ejections appear to have been basic lavas and tuffs, which are interstratified with flagstones and ashy sandstones; while, at a later period, great masses of felsitic lava were intruded into the older series, baking and hardening them, and injecting them with numerous veins of granite, felsite, and rhyolite.[1]

## Continental Equivalents.

In certain parts of Europe, notably in the Eifel district and that of the Belgian Ardennes, the Devonian system is very fully developed, and is less broken and contorted than it is in England, while at the same time the rocks are far more fossiliferous, so that a clearer conception of the whole succession can be obtained. The following is a tabular view of the succession in these two regions as correlated by Professor Gosselet:—

| | *The Eifel.* | *Belgium.* | |
|---|---|---|---|
| Upper. | Sandstones and shales with *Cypris serrato-striata* and other fossils. | Limestone with *Spirifer distans.* Shales with *Rhynch. letiensis.* Shales with *Rhynch. Dumonti.* Shales with *Rhynch. Omaliusi.* | Famennien.[2] |
| | Shales with *Cardium palmatum.* Marls and limestones with *Rhynch. cuboides* and *Receptaculites.* | Shales with *Cardium palmatum.* Shales and limestone with *Rhynch. cuboides* and *Spirifer disjuncta.* | Frasnien. |
| Middle. | Stringocephalus limestone. | Limestone with *String. Burtini.* | Givetian. |
| | Crinoid and Calceola limestones. | Limestone with *Calceola sandalina.* | Eifélien. |
| Lower. | Greywacke with *Spirifers.* Sandstones and schists. White sandstone. | Greywacke, sandstones and shales in five stages (*Spirifer cultrijugatus, Chonetes plebeia*), with white sandstones at the base. | Coblenzien. |
| | Arenaceous shales. Arkose resting on Silurian. | Shales in three stages. Arkose and conglomerate. | Gedinnien. |

## Physical Geography.

During this period great geographical changes took place; the greater part of Britain was elevated into dry

[1] Peach and Horne, "Trans. Roy. Soc. Edin.," vol. xxxii. p. 359.

[2] Professor Gosselet believes that the Psammite du Condros, which occupies a large area and is 1,800 feet thick, is the arenaceous representative of the Famennian, just as the Pickwell sandstones may represent the Petherwin beds in Britain.

land, and formed part of a continent, which must have had a considerable extention to the north and west of our islands. The sea which covered so large a part of the British area in Silurian times was now contracted into a much smaller space, and only lay over the southern part of England, whence it stretched eastward through the north of France and Belgium. Westward it seems to have extended into Ireland (if the Glengariff grits are marine beds), but can only have covered a comparatively small area in the extreme south-western part of the country.

All the rest of Ireland appears to have been land, and was doubtless united to England and Scotland across the Irish Sea. The border of this land ran through the west and north of Wales, and thence probably to the north-east through Derbyshire, all the north of England and south of Scotland being continuous land. It is probable, also, that a tract of land lay over the east of England, and of this the Charnwood Forest area may be a remnant; but between these eastern and western shores lay a long and gradually narrowing bay or inlet, in which the red sandstones of Monmouth, Hereford, and Shropshire were laid down. This inlet probably passed north-eastward into a narrow estuary, and may have received a river, draining the land which lay to the north; southward it opened into the sea where the marine Devonians were being deposited.

Scotland was for the most part lofty land, consisting of several mountain ranges, having a general north-east and south-west direction. Between these were low-lying tracts, which were at first inlets of the sea, but subsequently became large inland lakes. The sites of these lakes have already been indicated (p. 152), and similar lakes existed in the north of Ireland; that of Tyrone may possibly have been a continuation of Lake Caledonia, but the small tract of Lower Old Red recently discovered in Donegal was probably formed in a separate basin, which has been named Lake Fanad by Professor Hull. It is quite possible that there were lakes in the centre and south of Ireland during the earlier part of the period, but if so their sites are entirely concealed, the only lacustrine beds known to us in these areas being those of the Upper Old Red.

In the tracts which were covered by the sea there was

continuous deposition throughout the period, but in the lacustrine areas it appears to have ceased altogether for a time; there is a great gap between the Lower and Upper Old Red Sandstone, and we have no records of the intervening time. But this very absence of deposits is in itself evidence of the conditions which prevailed—the lakes must have been dried up and converted into land surfaces, probably in consequence of the continued elevation of the country, and the deepening of the river channels which would result from this elevation.

We may, therefore, conclude that the general succession of events in Scotland was as follows: at the beginning of the period the upheaval of the ridges which subsequently became mountain ranges contracted the sea-space into gulfs, which were gradually shallowed by the material poured into them from the land on either side, and by the continued upheaval of the country, till they were entirely isolated from the sea, and were converted into large fresh-water lakes, comparable to those of modern North America, and tenanted by a great variety of curious fish. Lake Caledonia must, indeed, have greatly resembled Lake Michigan, which has a length of 345 miles, and an extreme width of only 84 miles. Now the Scottish portion of Lake Caledonia has a length of 160 miles; and if, as Professor Hull supposes, it stretched continuously into North Ireland, we must add another 80 miles to its western extension, giving a total of 240 miles, while how far it extended to the east of Scotland we have no means of knowing, but it may well have been 300 miles in length, and its extreme width was probably about 80 miles.

During the existence of these lakes volcanic activity was rife, and immense sheets of lava were poured over the country and interbedded with the lacustrine deposits, and all this time it is probable that the lake bottoms were not more than three or four hundred feet above the sea. Further elevation, however, ensued, and the excurrent rivers cut their channels deeper and deeper, till in course of time the waters of the lakes were completely drained off, just as the great Tertiary lakes of North America were drained by the excavation of the Colorado Cañon. The country would then present the aspect of a high and dry

upland, formed of lofty hill ranges separated by immense sandy plains, the sites of the desiccated lakes; through these plains ran the rivers in deep and narrow channels, while on the mountain slopes piles of débris were prepared by the agencies of disintegration and detrition. It is, indeed, not unlikely that much of the material forming the conglomerates of the Upper Old Red Sandstone was originally prepared by subaerial agencies, and was only rearranged by the waters of the later epoch.

A reverse movement at length set in toward the end of what must be called the Devonian period; portions of the old lake-basins were again filled with water, the area of which widened and deepened as the land sank; torrents washed in the detritus of the land, and the material thus collected became the conglomerates and sandstones of the Upper Old Red and Lower Carboniferous series.

This depression led to the formation of a large lacustrine area in the south-west of Ireland, spreading over the tracts now known as the counties of Clare, Limerick, Kerry, Cork, Waterford, Tipperary, and Kilkenny. Its northern shore appears to have been somewhere along the parallel of Galway Bay; the Granitic and Ordovician rocks of Wicklow, Carlow, and Wexford formed its eastern boundary, while how far it extended to the south and west we have no means of knowing, except that in the Dingle and Kenmare districts we appear to be approaching its western shores. From Dingle to Thomastown in Kilkenny is a distance of 135 miles, and from Galway Bay to the Old Head of Kinsale is 108 miles; this would form a fine sheet of water, but even if it stretched another 100 miles to the southward, it would only have been about half the size of the modern Lake Superior.

In this lake were laid down the strata described on p. 160, and at the epoch of the Kiltorcan beds, it is evident that its shores were bordered by tracts of fertile land, on which grew the *Lepidodendra*, *Cyclostigmæ*, and the splendid ferns known as *Palæopteris hibernica*, the fronds of which were nearly two feet in breadth. Eventually the continued depression of the land brought the level of the lake waters down to that of the Carboniferous sea, which was gradually extending itself over the lower parts of the great Devonian continent.

## CHAPTER VI.

### The Carboniferous System.

#### Classification of the Rocks.

THE materials for a history of this period are more ample than those available for the preceding periods. Carboniferous rocks occupy a larger part of the British Islands than the rocks of any other system; they have also been more extensively studied and explored in the search for coal, so that it has become possible to trace the lateral changes which the component members of the system undergo, and to correlate the strata of different districts with some degree of accuracy.

Where normally developed, the Carboniferous system seems to be naturally divisible into four great groups or series, and the following classification is one which will apply more or less fully to the whole of England, Scotland, and Ireland, Devonshire and south-west Ireland only being excepted:—

| | | | Max. thickness. Feet. |
|---|---|---|---|
| Upper. | 4. Freshwater. | Upper Coal Measures | 2,000 |
| | | Middle Coal Measures | 4,000 |
| | 3. Partly Marine. | Lower Coal Measures | 2,000 |
| | | Millstone Grit | 5,000 |
| Lower. | 2. Carboniferous Limestone. | Upper Limestone Group<br>Middle Limestone or Calp<br>Lower Limestone or Tuedian | 8,000 |
| | 1. Basement Beds. | Red Conglomerates | 2,000 |
| | | | 23,000 |

Some of the sandstones and conglomerates formerly referred to the Old Red Sandstone are here included under the head of Tuedian, because they occasionally contain Carboniferous fossils, and are sometimes interstratified with limestones; such beds being evidently shore deposits

of Carboniferous age. The Carboniferous Limestone series forms a continuous sequence, and is more often separable into three groups than into an upper and lower group. The best marked line of division in the whole system is at the base of the Millstone grit, as indicated long ago by Professor Phillips and more recently by Professor Green. The Millstone Grit and Lower Coal Measures yield marine fossils, but both frequently contain seams of coal.

In the southern and central parts of England and Ireland the Lower Carboniferous rocks are entirely marine, and the limestones attain an enormous thickness; but as the beds are traced northward, the limestones decrease in thickness and admit intercalations of shales and sandstones, with occasional seams of coal, so that in Scotland there are alternations of marine and freshwater deposits throughout the whole series.

## Life of the Period.

The fossils of the Carboniferous rocks furnish us with representatives of both the marine and terrestrial types of life which flourished during the period, so that our acquaintance with the fauna and flora of the Carboniferous Period is much more complete than it is with those of the older systems. This being so, we may treat separately of the marine and terrestrial types.

1. **Marine Type.**—The most remarkable feature in the distribution of the marine fauna is the persistence of the same species and groups of species throughout such a great thickness of strata. A few species are indeed confined to the lowermost beds, and a few to the highest marine beds—to beds, in fact, which were formed when the physical conditions were undergoing a change, and when the forms would necessarily be most liable to variation; a few other species—those, namely, which were the chief contributors to the formation of the limestones—are naturally most abundant in those limestone masses; but by far the larger number of species have a very great vertical range, many of them extending from top to bottom of the marine series, and even appearing in the essentially freshwater and estu-

arine strata above and below wherever the temporary prevalence of marine conditions led to the formation of limestone (see list on p. 173).

We are thus presented with the unique phenomenon of the same species of fossils occurring throughout a thickness of from ten to fourteen thousand feet of strata—a fact which testifies to the great uniformity of the physical conditions which prevailed during the whole period. When we compare this state of things with the distribution of species in earlier or in later periods, we cannot fail to be struck with the singularity of the Carboniferous period in this respect. It would appear as if there was then a great pause in the evolutional history of the world—a time when the changes in the surrounding physical conditions were so slight and gradual that the causes of variation and differentiation were at a minimum, and the forms of life became as it were stereotyped for a time.

As regards the birth and extinction of generic forms during this period, the following are some of the more important changes:—

**Actinozoa.**—*Amplexus, Aulophyllum, Lithostrotion, Michelinia,* and numerous other genera of corals, date their existence from this period, and did not survive beyond it. Many other Palæozoic forms also died out, and became extinct at the close of the period. Of these the chief are *Alveolites, Clisiophyllum, Cyathophyllum, Favosites, Heliolites, Strephodes, Syringopora, Zaphrentis.*

**Brachiopoda.**—*Producta* and *Camarophoria* are the only generic introductions, and they both survived into the Dyas, while *Athyris, Chonetes, Orthis, Pentamerus,* and *Retzia* all became extinct in Britain.

**Lamellibranchiata.**—The following genera are to be noted as occurring for the first time: *Aviculopecten, Axinus, Cardinia, Cucullæa, Edmondia, Inoceramus, Monotis, Leda, Lucina* (?), *Myacites, Myalina, Pleurophorus, Schizodus. Aviculopecten* did not survive, and *Conocardium, Dolabra,* and *Sanguinolites* likewise disappear.

**Gasteropoda.**—Among new genera we have *Cylindrites, Dentalium, Littorina* (?), *Natica, Patella,* and *Platychisma. Pleurotomaria, Euomphalus,* and *Lozonema* continue to occur.

**Cephalopoda.**—Fresh introductions are few; *Goniatites*, *Posterioceras*, and *Nautilus* dating from the Devonian. So far as British rocks are concerned, all the *Orthoceratidæ* became extinct at the close of the Carboniferous period.

**Echinodermata.**—Crinoids are abundant, the principal genera being *Actinocrinus*, *Cupressocrinus*, *Poterio-*

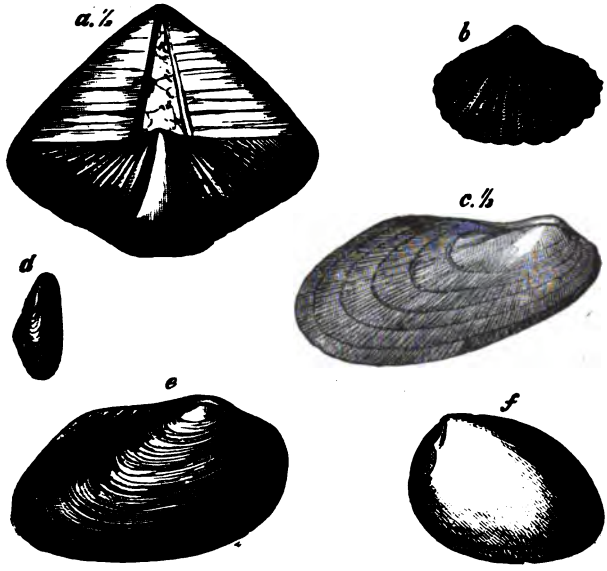



Fig. 29. Lower Carboniferous Fossils.

*a*. Spirifera cuspidata.
*b*. Rhynchonella pleurodon.
*c*. Avicula Damnoniensis.
*d*. Modiola Macadami.
*e*. Cucullæa Hardingii.
*f*. Curtonotus elegans.

*crinus*, *Cyathocrinus*, *Rhodocrinus*, *Taxocrinus*, and *Platycrinus*. A few such as *Adelocrinus* and *Woodocrinus* came into existence, but did not survive the period. The Blastoidea were represented by *Pentremites*, and the Echinidea by *Archæocidaris* and *Palæchinus*, the latter dying out.

**Crustacea.**—In this period the Trilobites, represented only by four genera, *Brachymetopus*, *Griffithides*, *Phillipsia*, and *Proetus*, finally become extinct.

**Fish.**—The following genera appear to be confined to the rocks of this period: *Cheirodus, Cladodus, Cochliodus, Ctenodus, Diplodus, Glossodes, Holoptychius, Megalichthys, Oracanthus, Orodus, Petalodus, Pterodus, Pleuracanthus, Pœcilodus, Psammodus, Rhizodus.* A few others, such as *Cœlacanthus, Platysomus,* and *Strepsodus,* survived its close.

The following lists contain the most characteristic fossils of the several stages in the marine part of the system:—

## Fossils of the Lowermost Beds.

(Carb. Slate; Limestone Shale; Pilton group.)

*Polyzoa.*—Fenestella antiqua,

*Crustacea.*—Leperdita subrecta.

*Brachiopoda.*—Lingula squamiformis, Chonetes Hardrensis, Streptorhyncus crenistria, Athyris ambigua, Spirifera cuspidata.

*Lamellibranchs.*—Avicula Damnoniensis, Cucullæa Hardingii, Curtonotus elegans, Modiola Macadami.

*Heteropoda.*—Bellerophon striatus.

In the marine shales of the Tuedian and Calciferous sandstone are Spirorbis carbonarius, Discina nitida, Lingula squamiformis, Bellerophon decussatus, and Orthoceras cylindraceum.

## Fossils of the Carboniferous Limestone.

*Actinozoa.*—Amplexus coralloides, Lithostrotion affine, L. junceum, L. striatum (= basaltiforme), Michelinia favosa, Zaphrentis cylindrica, Syringopora reticulata.

*Echinodermata.*—Pentremites Derbiensis, Platycrinus lævis, Poteriocrinus crassus, Actinocrinus amphora.

*Crustacea.*—Brachymetopus ouralicus, Phillipsia pustulata, Griffithides globiceps.

*Polyzoa,*—Fenestella antiqua, F. membranacea.

*Brachiopoda.*—Terebratula hastala, T. sacculus, Athyris ambigua, Spirifera striata, S. glabra, Rhynchonella acuminata, Producta gigantea, P. semireticulata.

*Lamellibranchs.*—Cardiomorpha oblonga, Pleurorhyncus Hibernicus.

*Gasteropoda.*—Natica plicistria, Euomphalus pentangulatus, Pleurotomaria carinata (flammigera).

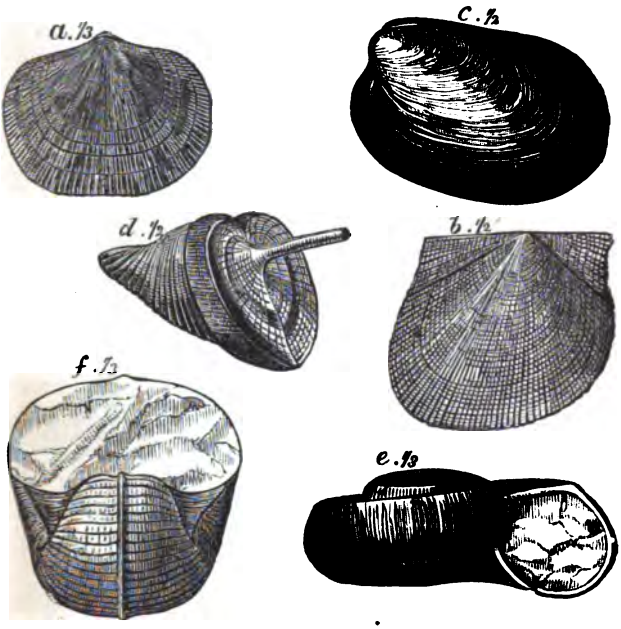



Fig. 30. Carboniferous Fossils.

*a.* Orthis resupinata.
*b.* Aviculopecten papyraceus.
*c.* Cardiomorpha oblonga.
*d.* Conocardium Hibernicus.
*e.* Euomphalus pentagonalis.
*f.* Bellerophon tangentialis.

*Cephalopoda.*—Nautilus carinatus, N. dorsalis, Goniatites Listeri, Cyrtoceras Gesneri.

*Pisces.*—Psammodus porosus, Orodus ramosus, Pæciodus Jonesii.

The fossils of the Yoredale beds are essentially the same as those of the Lower Limestone series; but the chief lime-

stone-making genera are much less common, as might be expected, while Lamellibranch Mollusca are proportionally more abundant. The following are the species most commonly met with in the Yoredale group: Woodocrinus macrodactylus, Posidonomya Becheri, Ctenodonta sp., Aviculopecten papyraceus, Av. variabilis, Goniatites Listeri, G. crenistria.

The Millstone grit is generally barren of fossils, but when they do occur they are of Yoredale and Carboniferous Limestone species.

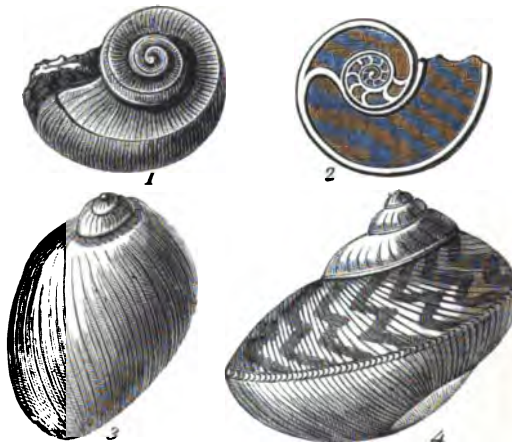


Fig. 31. Carboniferous Fossils.

1. Euomphalus pentagonalis (from above). 3. Natica plicistria.
2. „ „ (section). 4. Pleurotomaria flammigera.

## Fossils of the Lower Coal Measures.

The fauna of this group indicates a transition from the marine conditions of the lower stages to the estuarine and freshwater conditions of the overlying measures. Apart from the plants its fossils are chiefly marine, and the following are some of them:—

*Brachiopoda.*—Discina nitida, Lingula mytiloides, Athyris pinguis.

*Lamellibranchs.*—Axinus sulcatus, Monotis lævis, Schigodus carbonarius, Posidonomya Gibsoni, P. membranacea.

*Cephalopoda.*—Goniatites reticulatus, G. Gibsoni, Orthoceras Steinhaueri.

The principal marine fossils are given in the preceding

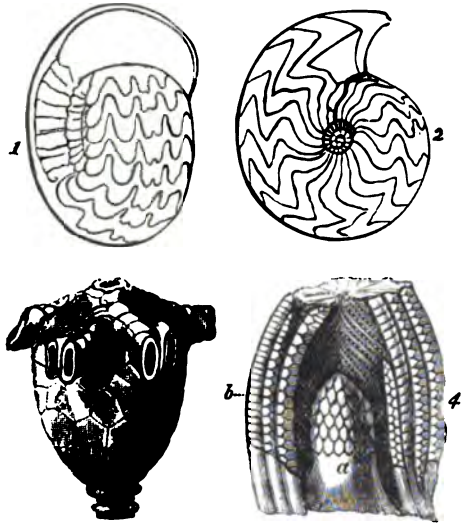



Fig. 32. Carboniferous Fossils.

1. Goniatites Listeri.
2. ,, crenistria.
3. Actinocrinus Parkinsoni.
4. ,, (arms and proboscis).

lists, but there are many species which, though perhaps more abundant in one group than in others, nevertheless range throughout the whole marine series. The following are some of these:—

| | |
|---|---|
| Discina nitida, | Athyris planosulcata, |
| Rhynchonella pleurodon, | ,, ambigua, |
| Orthis resupinata, | Producta scabricula, |
| Spirifer pinguis, | ,, semireticulata, |

Aviculopecten papyraceus, Goniatites sphæricus,
Conularia quadrisulcata, Phillipsia pustulata.
Bellerophon Urii,

**2. Terrestrial and Freshwater Type.**—This fauna and flora is of course found principally in the true Coal-measures, but the same genera and often the same species occur in the estuarine and freshwater beds which are prevalent throughout the whole system in Scotland, and to a less extent in the north of England.

*Ferns.*—Fern-leaves abound in almost every coal-seam and its associated measures, the coal-roof being sometimes completely covered with the impressions of beautiful fronds. It is difficult to say how many of the fronds belonged to stemless ferns, or whether the majority are not the fallen leaves of arborescent ferns, resembling the tree-ferns of the tropics. Stems of such tree-ferns have been found resembling some recent forms in the size and disposition of the scars left by the detachment of the frond stalks. Fronds bearing fructification are occasionally found, but most of the present genera are distinguished only by the nervation and form of the pinnules (or leaflets), characters which are sufficient for the distinction of species, but are not trustworthy guides in the grouping of species into genera.

Among the genera which have been founded on the barren fronds, the following are some of the most abundant:—*Alethopteris* (fig. 33), *Neuropteris* (fig. 34), *Palæopteris*, *Pecopteris*, *Odontopteris* (fig. 33), *Sphenopteris* (fig. 33), *Sagenopteris*, *Cyclopteris*.

*Calamites* were gigantic Equiseta or Horsetails, and consisted of a large central column of soft tissue encased in a cylinder of woody tissue or bark. The central part has generally perished and disappeared, and the cavity thus left has been filled up with mineral matter, forming the casts which are such common carboniferous fossils. The outer ligneous envelope, being carbonized and friable, is seldom preserved in a perfect state.

The stellate markings round the stem in fig. 34, are the impressions of a zone of leaves surrounding the joint.

The name *Calamites* is at present restricted to these

Fig. 33. Carboniferous Ferns.

1. Sphenopteris linearis.
2. „ affinis.
3. Alethopteris lonchitica.
4. Odontopteris Schlotheimi.

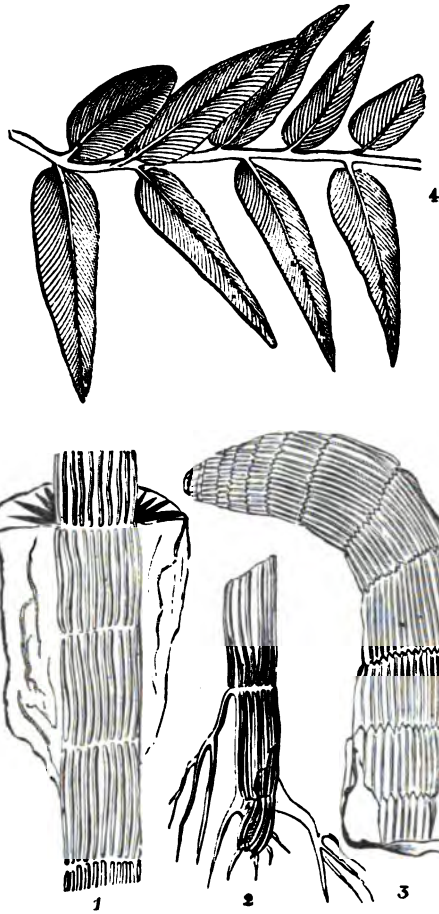



Fig. 34. Carboniferous Plants.

1, 2. Calamites radiatus (stem and roots).
3. ,, approximatus (base uppermost).
4. Neuropteris acuminata.

jointed stems, while other names, *Asterophyllites*, *Annularia*, and *Sphenophyllum*, are given to different varieties of foliage which are believed to belong to *Calamites*. The fruit is a scaly spike (*Volkmannia*), in which sporangia are arranged like those of Equisetum.

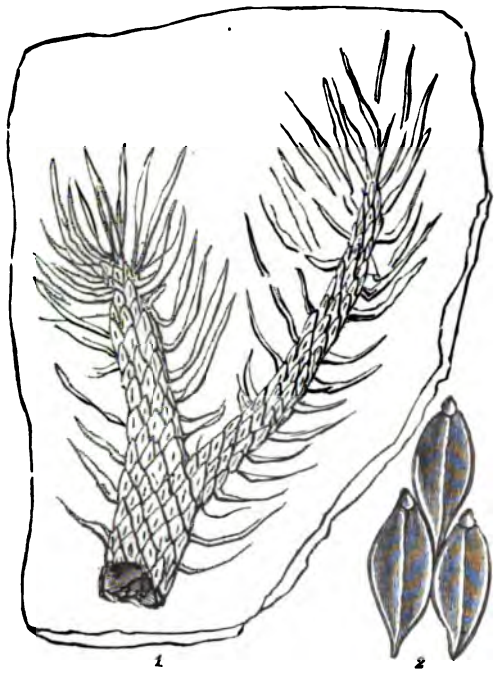



Fig. 35. Lepidodendron.
1. A terminal branch. 2. Leaf scars from the stem.

*Lepidodendra.*—These were gigantic members of the Lycopodiaceæ, or Club-moss family, having trunks many feet in girth, and forty to sixty feet in height. The trunks branch toward the top into several limbs, which divide again into smaller boughs. The foliage consists of simple linear leaves, which are sometimes found attached to the

terminal branches (fig. 35), and the angular scars on the stem are the marks left by the detachment of these leaves.

The scaly cylindrical cones which are known as *Lepidostrobi* are the fruit of the Lepidodendra, and were borne at the extremities of some of the branches.

*Sigillaria.*—These appear to have been the commonest trees in the swampy portions of the Carboniferous forests, and have evidently supplied the chief mass of the material which forms our coal-seams, while their roots (*Stigmariæ*) ramify in the under-clays beneath. They were tall trees, branching at the top, and rivalling the Lepidodendra in height, with a bare trunk fluted longitudinally, and regularly ornamented by the pits or scars left at the points where the leaf-stalks were attached. These leaves were long and narrow, and were first described under the name of *Cyperites*. The fruit consists of small sporangia borne at the basis of slightly modified leaves; *Sigillaria* was therefore an Acrogen, and allied to *Lepidodendron*. The roots (*Stigmariæ*) were long, branching, and tapering, with numerous radicles spreading out in all directions; such roots have been found which were upwards of twenty feet in length. Perhaps, like those of the modern mangrove-tree, these roots were partly aerial, rising well above the low-water mark of the swamp, and uniting in a dome-shaped manner to support the trunk.

*Coniferæ.*—The stems of true Coniferæ (*Pinites, Dadoxylon, and Araucarioxylon*) have also been met with, especially in the volcanic tuffs of the Scotch Carboniferous series; the lower slopes of the old volcanoes were doubtless clothed with these pine-trees, their habitat being in such high and dry localities, and not in the swampy ground where the other plants flourished. The fruit called *Trigonocarpon*, of which there are many forms abounding in the Coal-measures, are now supposed to have belonged to conifers of the yew tribe.

*Mollusca.*—In the Coal-measure shales, and associated with many of the plants above-mentioned, shells somewhat resembling the recent Unios are frequently found. They have been referred chiefly to three genera, *Anthracosia, Anthracomya*, and *Anthracoptera*; but their real affinities

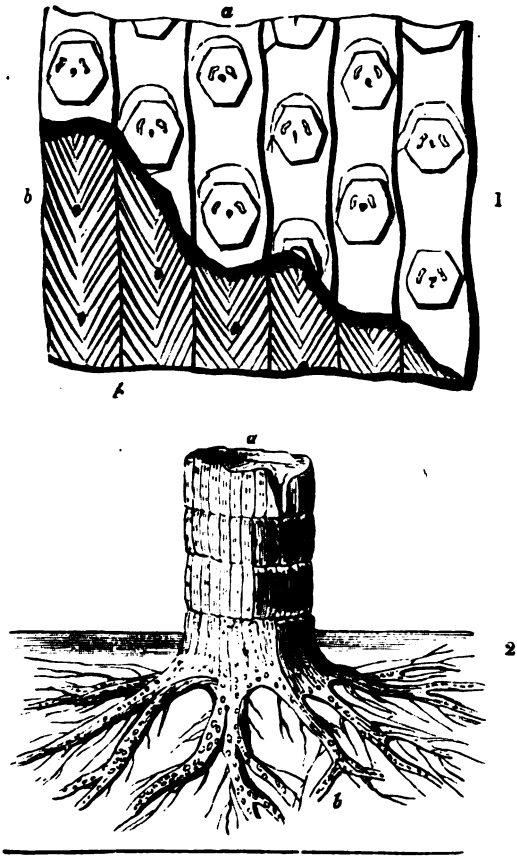



Fig. 36. Sigillaria and Stigmaria.

1. Sigillaria Saulii, bark (*a*), and inner surface (*b*).
2. Sigillaria stem (*a*), with Stigmarian rootlets (*b*).

are not known, and they appear to have been capable of living both in fresh and brackish water, if not in purely salt water, for the same species are sometimes found associated with marine mollusca.

*Arthropoda.*—True insects, Myriapods and Arachnids, have also been found in the Coal-measures, including crickets, beetles, and a scorpion. Crustacea also inhabited the waters, the small Ostracoda—*Leperditia*, *Beyrichia*, and *Estheria*—swarming in some localities, as in the Burdiehouse Limestone (p. 205), and several species of Limuloid Crustacea have been described by Dr. Woodward, and referred to the genera *Limulus* and *Belinurus*.

*Fishes.*—Fish remains, of Ganoid and Elasmobranch genera, are everywhere abundant, but it is difficult to separate entirely the freshwater forms from the marine, because some (like the Mollusca) seem to have been equally at home in salt and brackish water; some of them, like the modern salmon, may have lived in the sea at certain seasons and in the estuaries and rivers during other parts of the year. The following genera are, however, most frequently associated with the Coal-measure plants:—*Cœlacanthus*, *Cheiradus*, *Ctenacanthus*, *Ctenoptychius*, *Gyracanthus*, *Megalichthys*, *Platysomus*, *Pleuracanthus*, *Rhizodus*, *Rhizodopsis*, and *Strepsodus*.[1]

*Amphibia.*—Thirteen genera of Labyrinthodonts are recorded from British Carboniferous rocks, *Anthracosaurus*, *Loxomma*, *Ophiderpeton*, *Urocordylus*, &c., mostly from the Jarrow coalfield in Leinster, Ireland. Others (*Archegosaurus*) occur in Prussia and (*Baphetes*, *Dendrerpeton*) in Nova Scotia. Footprints have also been observed in the Forest of Dean coalfield and in the Limestone Series of Dalkeith, Scotland. The larger reptiles are believed to have measured seven or eight feet in length, but others were very small; they were probably fluviatile creatures preying on the fish and crustacea which swarmed in the swamps and lagoons of the period.

[1] Dr. Traquair considers that the genera *Palæoniscus*, *Amblypterus*, and *Pygopterus* are Permian forms only, and that the Carboniferous fish described under these names belong to other genera.

*Range and Relation to Underlying Rocks.*

In England Carboniferous rocks occupy large tracts of the surface, and also have a wide subterranean extension. They form the eastern part of Devonshire, and underlie a large area round Bristol, though partially concealed by beds of newer date; westward they extend under the Bristol Channel into South Wales, and across Carmarthen Bay into Pembroke; eastward they pass beneath newer rocks, and are believed to extend through the counties of Wilts, North Hants, and Surrey, forming part of the broad tract of Palæozoic rocks which is known to exist beneath the Cretaceous beds under and north of London.

They have also a wide subterranean extension in the Midland counties, having been proved beneath the Mesozoic strata at Burford in Oxfordshire, and at Northampton, and portions of them reach the surface in the coalfields of Warwick, Leicester, and Stafford. They form also a nearly continous band along the borders of Wales through Worcester and Shropshire, and through the counties of Denbigh and Flint to the estuary of the Dee.

In the north of England they form the whole length of the Pennine chain from Derbyshire to Northumberland, and occupy large surface areas on either side; they are moreover supposed to underlie all the tracts covered by newer rocks in this part of the country, so that they are only really absent from the Lake District and the few other localities where older beds rise to the surface.

From Northumberland they spread into Scotland through the counties of Berwick and Haddington, and thence into the Lowland District, which they occupy entirely from side to side.

In Ireland they form more than half the rock-surface of the country, spreading over the whole central plain from sea to sea, and stretching southward to the shores of Waterford and Cork.

In regard to superposition, it may be stated generally that where rocks of Upper Devonian age are developed, the Carboniferous strata succeed in conformable sequence, but where the marine Devonians are absent, the Carboniferous

rocks usually rest irregularly and unconformably upon a surface of the older Palæozoic rocks. Where, however, the Upper Old Red Sandstone is found, this statement is not true, unless the whole of that series is included within the Carboniferous system; if only a part is so included (as in Scotland), then the relation between the Carboniferous and Old Red Sandstone is a conformable one.

Where the lower members of the system are absent, as is the case in the Midland counties of England, there is a very marked unconformity, and the upper members rest on an irregular surface of Silurian and Ordovician rocks. Again, where no rocks of Devonian age occur, as in Lancashire and Westmoreland, the Carboniferous base rests on the upturned edges of older rocks.

The upper members of the system also frequently overlap the lower, as in South Wales and Shropshire.

### *Stratigraphy.*

For the purposes of description I shall treat of the several districts in which Carboniferous rocks occur in the following order:—

1. South-Western area.
2. The Midlands.
3. North Wales.
4. South Pennine area.
5. North Pennine area.
6. The Lake District.
7. Scotland.
8. Ireland.
9. Devonshire.

### 1. South-Western Area.

Passing over for the present the tract of Carboniferous rocks in Devonshire, we commence with the area which includes the Bristol, Forest of Dean, and South Wales coalfields. Carboniferous rocks set in along the range of the Mendip Hills which display an anticlinal of Old Red Sandstone covered by Carboniferous Limestone series, the northern slopes of the latter dipping beneath the strata of the Bristol coalfield.

In this district the Palæozoic rocks are partially con-

cealed by a greater or less thickness of newer strata (Trias, Lias, and Oolites), and are only exposed to view in disconnected and isolated tracts where the younger strata have been removed; but the general structure of the area is well known from the explorations of mining enterprise. In shape the Bristol coalfield forms an irregular triangle, and is divided into four separate basins by two anticlinal axes, which cross each other to the west of Bristol, one running nearly due east and west, the other from S.S.W. to N.N.E. The two eastern basins are the largest and most important. The Carboniferous Limestone and Millstone Grit are continuous round the whole area.

Crossing the Severn we find a tract of Lower Carboniferous rocks in the neighbourhood of Chepstow, which stretches northward and ties on to the periclinal area that encloses the coalfield of the Forest of Dean, a perfect example of a basin-shaped area.

Passing westward, and crossing the tract of Silurian and Old Red Sandstone which lies on either side of the river Usk, we come to the great coalfield of South Wales. Here the Carboniferous rocks occupy a long basin or trough-shaped area, which extends from Pontypool in Monmouthshire to Carmarthen Bay, with a narrow prolongation across this bay through Pembrokeshire to St. Bride's Bay. The area east of Carmarthen Bay is traversed by a remarkable anticlinal axis which divides the basin into a northern and southern trough.

The strata composing the Carboniferous series are thickest in the south-eastern part of the area, and diminish partly by thinning out, and partly by overlap towards the west and north. The following is an account of the rock groups recognized in the area:—

**Red Sandstone Group.**—These form the upper part of the Old Red Sandstone series, and consist of red sandstones and conglomerates, see fig. 26. They form the central and sterile portions of the Mendip Hills, and surround the South Welsh basin, where they are more than 600 feet thick. They are believed to rest unconformably upon the Cornstone series, but this has not been ascertained definitely. They pass up into the overlying group, the passage beds consisting of red and yellow sandstones interstratified with

red, green, and grey shales, which are well exhibited on the Pembrokeshire coast.

**Carboniferous Limestone Series.**—This commences with a group of dark grey shales passing by alternation into the sandstones below and into the limestones above. It is finely shown in the gorge of the Avon at Clifton, where it is said to be about 500 feet thick, and contains near the base a remarkable bed crowded with the remains of fish in the shape of teeth and bones, and hence termed the "bone bed." In South Wales this Lower Limestone Shale is from 300 to 400 feet thick; in the Forest of Dean only 160 feet. In these shales marine fossils are abundant.

This shaly zone is succeeded by massive limestones, which have a thickness of 2,500 feet near Bristol, and 1,000 feet in Glamorgan, but thin westward, and die out altogether near Haverfordwest. They likewise thin northward, and in the Forest of Dean are only 680 feet thick, and include a thick red sandstone near the top. Where the group is fully developed its lower portion consists of massive bluish grey limestones, full of corals, encrinites, and brachiopoda (see list on p. 170); the central portion of dark shales, succeeded by more massive limestones; the uppermost 500 or 600 feet consist of thin limestones, alternating with black and brown shales, and occasional beds of red sandstone near the top; these upper beds probably represent the *Yoredale Group* of the northern counties.

The following is an abstract of a section measured by Sir H. De la Beche from Brandon Hill to the Avon near Bristol[1]:—

| | | Feet. |
|---|---|---|
| Millstone Grit | | 975 |
| Limestone Series. | Upper shales and limestones | 500 |
| | Massive limestones | 448 |
| | Dark shales | 477 |
| | Lower limestones | 766 |
| | Lower limestone shale | 411 |
| Yellow sandstones with a basement layer of quartz pebbles | | 294 |

[1] "Mem. Geol. Survey," vol. i. p. 122.

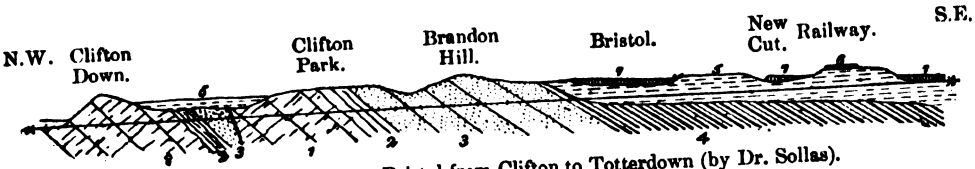



Fig. 37. Section across Bristol from Clifton to Totterdown (by Dr. Sollas).

Distance about 3 miles.

1. Lower and Middle Limestones.
2. Upper Limestone and Shale.
3. Millstone Grit.
4. Coal-measures.
5. Trias.
6. Lower Lias.
7. Alluvium.

* * Sea Level.

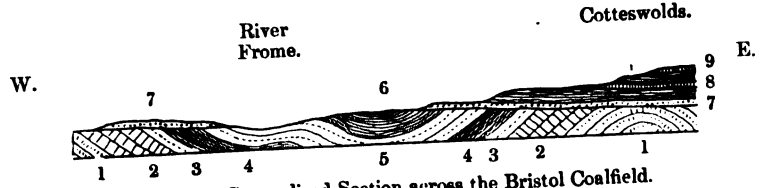



Fig. 38. Generalized Section across the Bristol Coalfield.

Distance about 10 miles. The anticlinal below the Cotteswolds is a theoretical insertion.

1. Red Sandstones.
2. Carb. Limestone.
3. Millstone Grit.
4. Lower Coal-measures.
5. Pennant Grits.
6. Upper Coal-measures.
7. Trias.
8. Lias.
9. Inf. Oolite.

**Millstone Grit.**—The "Limestone Series" is succeeded by the thick grits or sandstones which are generally known as the Millstone Grit, but in South Wales are called the Farewell Rock, because when this is struck it is equivalent to saying "farewell" to the Coal-measures. Near Bristol these grits are estimated at 950 feet in thickness, but in South Wales they never exceed 350 feet, and thin westward so rapidly, that they are entirely absent to the west of Swansea Bay, allowing the Lower Coal-measures to rest directly upon the Carboniferous limestone, and when this thins out also near Haverfordwest, the higher beds repose upon Lower Silurian rocks.

**The Lower Coal-Measures** are principally shales, but are rich in ironstones and coal-seams, the latter being most numerous in the Bristol coalfield, where the series is some 2,000 feet in thickness, and along the southern outcrop of the Welsh area, where it has a thickness of 1,000 feet, northward and westward it thins to less than 500 feet.

**The Pennant Grits** overlie the Lower Coal-measures, and consist chiefly of hard thick-bedded sandstones, but containing from five to fifteen coal-seams with their underclays. This series attains its maximum development in Glamorganshire, where it is estimated at more than 4,000 feet, and forms the fine range of escarpments which enclose the central table-land of the county. In Gloucestershire it is about 2,000 feet thick. In the Forest of Dean the productive measures are 1,900 feet thick, and probably include representatives of the Lower and Middle Coal-measures.

**The Upper Coal-Measures.**—These consist of shales and sandstones, with many coal-seams, nine of which are over two feet thick: the whole series has a thickness of 3,000 feet near Bristol, and more than this in South Wales. They form the great table-land of Glamorganshire, and "along the deep valleys by which this region is intersected the coal-beds often crop out, and are worked by tunnelling into the heart of the hills" (Hull). In South Wales the character of the coals undergoes a remarkable change as they are followed from east to west, the same seams which are bituminous in the east becoming semi-bituminous in

the central area, and finally passing into the hard anthracites of Pembrokeshire.[1]

## 2. The Midland Area.

In the central part of England the lower groups of the Carboniferous series are for the most part wanting, and the higher measures are broken up into a number of independent basins. Along the southern borders of these basins the Coal-measures rest unconformably upon the eroded edges of the older Palæozoic strata, but as they are traced northward some of the lower members of the system are found to set in again; in other words, the higher stages successively overlap those beneath them in a southerly direction.

The only complete sections of the system are at the extreme western and eastern limits of the area, near Coalbrookdale on the one hand, and near Charnwood Forest on the other. It will be convenient to commence with the former, and to add brief notices of the beds composing the Shropshire, Worcestershire, South Staffordshire, Warwickshire, and Leicestershire coalfields.

A traverse from the foot of the Wrekin, across Coalbrookdale, would pass over the edges of the Carboniferous beds, all dipping eastward, though broken by numerous faults. The succession is as follows, though, of course, in coming from the west, the lowest bed would be the first to be met with.

| | Thickness in N. part. |
|---|---|
| Upper Coal-measures . . . . | 300 |
| Middle Coal-measures } Lower Coal-measures } . . . | 1,000 |
| Millstone Grit . . . . . | (?) 300 |
| Carboniferous Limestone Series . . | (?) 250 |
| Basalt, resting on Silurian rocks . . | (?) 50 |

The Shropshire coalfield appears as usual to be basin-shaped, its eastern lip being covered unconformably by

[1] See Hull's "Coalfields of Great Britain."

Dyassic and Triassic rocks. The most interesting fact connected with it is the break or discordance in the middle of the Coal-measures, probably in consequence of the local absence of the middle stage of these measures; the upper measures, with a band of limestone containing *Spirorbis carbonarius*, being within 150 feet of the Millstone Grit at the south end of the coalfield.

As the lower members of the series are traced southward, it is found that the Millstone Grit quickly overlaps the underlying limestone and basalt on to the Silurian rocks, and though the grits continue to form a base for some distance, yet finally they also disappear, and in Worcestershire the Coal-measures rest directly upon the older rocks (Cornstone Series), extending southward in a narrow tract which broadens out near Bewdley. Moreover, these measures chiefly belong to the uppermost stage, which has therefore overlapped all those below. The same overlap appears to take place both in a westerly and easterly direction from Coalbrookdale; thus, near Shrewsbury, we have Upper Coal-measures only resting on Silurian and Cambrian rocks; while eastward, in South Staffordshire (where they rise again from below the newer rocks), representatives of the Coal-measures—Upper (800 feet), Middle and Lower (500 feet)—are the only surviving portions of the series, and these rest upon a very irregular surface of Silurian rocks. (See diagram, fig. 39.)

The same is the case in Warwickshire, where the Middle Coal-measures are faulted against the Cambrian shales, which were formerly supposed to represent the Lower Coal-measures (see p. 72). The productive measures (middle stage) are 1,400 feet thick, consisting of shales and sandstones, with five workable coal-beds near the centre, which coalesce towards the south into one compound seam 26 feet thick. Fifty feet of the Upper Coal-measures succeed, and contain a band of Spirorbis limestone, dipping everywhere beneath a large area of Permian rocks, which doubtless conceal a much larger coalfield than that exposed to view.

It is noteworthy that the thin band of limestone, containing *Spirorbis carbonarius*, and known as the Spirorbis limestone, is persistent over a very large area, although it

is seldom or never more than one foot thick. It was first detected in Shropshire by Sir Roderick Murchison, and has since been discovered in the Shrewsbury, Forest of Wyre, Staffordshire, Warwick, Lancashire, and North Wales coal-fields, always occupying the same position near the base of the Upper Coal-measures. It is remarkable, both as an instance of the persistence of a very thin stratum, and also as showing the widespread uniformity of conditions prevailing at the time of its formation.

In Leicestershire, as already mentioned, we once more find a complete section of the Carboniferous system, though the lower members thereof are very thin, and evidently not far from their original limits. The Carboniferous Limestone is exposed in several small detached areas, and its base is nowhere seen, but it probably rests on the Cambrian, or on the rocks which rise to the surface in Charnwood Forest. The overlying beds are as follow :—

| | Feet. |
|---|---|
| Sandstone (of Upper Measures) in unconformable outliers . . . . | 50 |
| Middle Coal-measures . . . . | 1,500 |
| Lower Measures, without coals . . | 1,000 |
| Millstone Grit . . . . . | 50 |
| Shales, blue, black, and purple . . | 40 |
| Carboniferous limestone. | |

### 3. North Wales.

A strip of Carboniferous rocks passes through the counties of Denbigh and Flint from the valley of the Severn south of Oswestry to the estuary of the Dee. The basement beds (Carboniferous limestone, &c.), which thicken considerably northward, rest upon Silurian rocks, and form a range of lofty hills, with terraced escarpments, facing the west. A powerful fault parallel to the valley of the Clwyd brings them in again under the Trias on the western side of that valley, and thence the limestone skirts the coast to Llandudno, where it forms the promontory of the Great Ormes Head. Small detached tracts of Carboniferous strata occur in Anglesey and on either side of

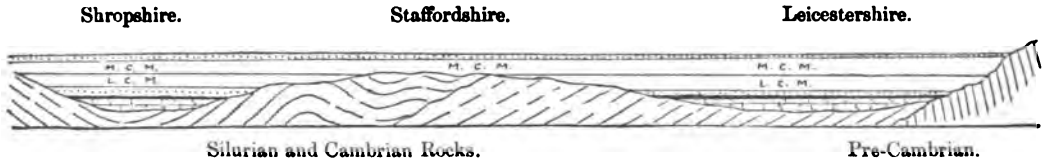



Fig. 39. Diagram to explain the manner in which the Carboniferous Strata were deposited upon an uneven surface of the older rocks in the Midland Counties, and showing the gradual submergence of the Staffordshire tract, which was an island or promontory between two gulfs in Lower Carboniferous times.

L.C.M. = Lower Coal-measures. M.C.M. Middle Coal-measures.

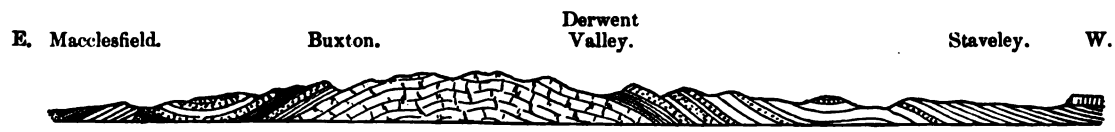



Fig. 40. Diagrammatic Section across Derbyshire, reduced from the Sections of the Geological Survey. Distance about 35 miles.

*a*. Carboniferous Limestone.
*b*. Yoredale Beds.
*c*. Millstone Grit.
*d*. Lower Coal-measures.
*e*. Middle Coal-measures.
*f*. Permian Rocks (Dyas).

the Menai Straits, including a complete series from the base to Middle Coal-measures.

**Tuedian Series.**—Red sandstones, with a base of quartz conglomerate resting on Cambrian, are found beneath the limestone in Anglesey, and similar beds crop out from Colwyn Bay along the west side of the Vale of Clwyd, but are overlapped by the limestone toward the south. Pebbles of Ludlow and Tilestone have been found in them.

**The Limestone Series.**—In North Flintshire this series is probably 2,000 feet thick; at the top is a group of thin-bedded black limestones and shales, containing *Fenestella* in abundance, with ferns and *Posidonomya Becheri*, and probably representing the Yoredale division. In South Flintshire this black limestone group is not recognizable, but the upper part of the limestone series is split up by beds of grit, with quartz pebbles and calcareous sandstones, which form a passage up into the Millstone Grit. In Denbighshire the limestones are from 1,000 to 1,500 feet thick, and include a set of shaly beds at the top. In Anglesey the thickness is greatly diminished, the limestone being only about 450 feet thick, and including a bed of sandstone.

**The Millstone Grit.**—In Denbighshire this is said to be of the normal type, and to be 800 feet thick, but in Flintshire it undergoes curious modification; in the south of the county it is still a coarse grit, full of quartz pebbles, but northwards beds of chert come in, and it finally passes into bedded chert of a fine and compact character, and about 300 feet thick.[1] In Anglesey it is represented by 200 feet of red sandstone and conglomerate.

**The Lower Coal-Measures** contain several coal-seams, with roofs of black shale, in which marine fossils occur; these correspond with the Gannister coals of Lancashire. The total thickness of the measures is about 1,000 feet in Flintshire, and they can be examined in a brook section south of Hope.

[1] For the above description of the Limestone and Millstone Grit in Flintshire I am indebted to my colleague Mr. A. Strahan. See "Mem. Geol. Survey," Explanation of Sheet 79 N.W.

**The Middle Coal-Measures** are about 800 feet thick, and contain nine or ten good coal-seams, with several beds of ironstone. A similar series is found in Anglesey.

**The Upper Measures** are only found in Denbigh and Flint, where they attain a thickness of more than 1,000 feet. The following is an abstract of the succession given by Mr. D. C. Davies[1]:—

| | | Feet. |
|---|---|---|
| Permian—Dark Red Sandstone. | | |
| Upper Coal-Measures. | Dark grey and blue shales, with a coal-seam | 180 |
| | Yellowish and greenish grey sandstones, with lenticular masses of limestone | 60 |
| | Blue shales, with two coal-seams and thick fireclays | 44 |
| | Red, white, yellow, and brown marls | 300 |
| | Green and grey grits and conglomerates, with red marls and clays | 300 |
| | Red and blue shales with ten thin coals and beds of green and brown sandstone | 220 |
| | Band of Spirorbis limestone | 1 |
| | Cefn shales and rock | 150 |
| | | 1,255 |

### 4. South Pennine Area.

From the central plains of England there rises gradually the broad range of ridges, peaks, and moorlands which is known as the Pennine chain. Commencing in Derbyshire, it runs northward through Yorkshire, Durham, and Northumberland to the Cheviots, and is entirely composed of Carboniferous rocks, which however exhibit remarkable lithological changes as they are followed from south to north.

In this section we shall describe the southern type—the rocks which form the Derbyshire Hills and the West

[1] "Quart. Journ. Geol. Soc.," vol. xxxiii. p. 10.

Riding of Yorkshire, including the great flanking coalfields of North Stafford and Lancashire on the west, and those of Nottingham, Derby, and Yorkshire on the east.

The general structure of Derbyshire is shown in fig. 40, the strata being bent up into a broad irregular dôme or periclinal ellipse, so that the lowest beds are found in the centre of the tract, and thence they dip steadily to the east and west, allowing higher and higher groups to take the ground. This dome passes northward into a narrower anticlinal axis separating the coalfields of Yorkshire and Lancashire. This anticlinal and the flanking synclinal troughs which form the coalfields are terminated by a cross-fold ranging roughly east and west, and bringing up the lower beds from beneath the Coal-measures, as may be seen on any geological map. This cross-fold is one of a series of parallel folds which traverse the Yorkshire moorlands, where the valleys are excavated through the Carboniferous Limestone Series, and are separated by ridges of Millstone Grit corresponding with the synclinal axes.

**The Carboniferous Limestone Series.**—The lowest beds of this series are limestones, the base of which is not seen in Derbyshire, although they are deeply trenched by many picturesque valleys, but their thickness on the Staffordshire side is estimated at 4,000 feet. These massive limestones occupy an irregularly oval area between the valleys of the Dove and Derwent as far north as Castleton, where the northerly dip of the periclinal sinks them beneath the overlying shales and grits.

They occur again, however, in West Yorkshire, forming three separate tracts ranging east and west, and brought up by so many anticlinal flexures with east and west axes: these tracts are (1) between Clitheroe and Skipton; (2) from Ingleton by Malham Water to Hartlington; (3) between Hawes and Middleham in Yoredale. In these localities the lower part of the series consists of massive limestones 3,000 feet thick, which near Ingleton and Malham Tarn are seen to rest directly on Silurian rocks; but the higher beds are separated by thin layers of shale and sandstone.

The limestones are succeeded by a series of shales and sandstones which were called the Yoredale series by Pro-

fessor Phillips, but which are now regarded by the Geological Survey as inseparable from the Limestone series, and as the equivalent of the upper part of this series elsewhere. In the south-east of Derbyshire there are only some 350 feet of shale which can be assigned to this group, but it thickens so rapidly westward that in North Staffordshire it is 3,000 feet thick, and can be subdivided as follows:—

Upper. Greenish shales, with a thick bed of sandstone (Yoredale Grit).
Middle. Fine grained sandstones.
Lower. Black shales, with thin bands of black limestone.

In the north of Derbyshire the group is about 1,400 feet thick, and in Lancashire it attains a great thickness, estimated at 4,400 feet, consisting of shales and flagstones with thin limestones and seams of coal. The thickness again decreases to the north-east, and is not more than 1,500 feet in Wharfedale and Yoredale, where these beds border the limestone tracts above mentioned.

**The Millstone Grit** consists of several sets of grits and flagstones separated by shales of varying thickness; like the Yoredale series its thickness increases to the north-west, and finds its maximum in East Lancashire, where it is said to be over 5,000 feet thick. Throughout the North Derbyshire and Lancashire area the following subdivisions can be traced, though the thickness of each varies greatly:—

5. Rough Rock, or first grit.
4. Shales.
3. Middle Grits, including the second and third grits of Derbyshire.
2. Shales.
1. Kinderscout Grit, or fourth grit.

The lowest grit takes its name from the high table-land of Kinderscout in the Peak country, which consists of this rock, and rises to a height of 2,000 feet above the sea. The middle grits are not so continuous as the upper and lower, but come in as lenticular beds at different horizons. The Rough rock is a very coarse grit, sometimes passing into a conglomerate of small quartz pebbles. In Lancashire

it contains a workable coal-seam called the "Feather-edge coal." The shales below also include thin seams of coal. To the south-west in Staffordshire the Kinderscout Grit is absent, and the group consists of the first and third grits only, with intervening shales, less than 400 feet altogether. Between Biddulph and Macclesfield the other grits come in and thicken rapidly northward, till near Mottram the whole group is 2,500 feet thick, and near Burnley over 5,000.

Fig. 41 shows the succession of shales and grits forming the Yoredale and Millstone Grit series near Crich in Derbyshire, where their combined thickness is about 700 feet.

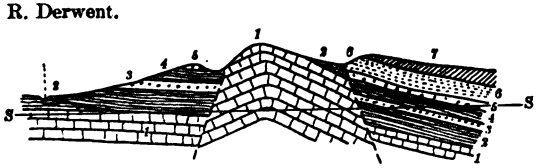



Fig. 41. Section through Crich Hill.

5, 6, 7. Millstone Grit.
2, 3, 4. Yoredale group.
1. Limestone group.
S. S. Sea-level.

In West Yorkshire the Kinderscout Grit forms the great escarpment of Gragreth, and caps the outlying eminences of Ingleborough, Whernside, and Mickle Fell.

**The Lower or Gannister Measures** consist of thick shales and sandstone, with several seams of coal and floors of a peculiar hard and compact siliceous stone which is locally known as "gannister." Some of the seams occurring in this and the overlying measures can be identified on both sides of the Pennine range, and thus testify to the original continuity of the Coal-measures over the whole district before these hills came into existence. The fossils, except in the coal-seams, are chiefly marine.

**Middle Coal-Measures.**—These consist of shales and sandstones, with numerous beds of coal and ironstone. Though commercially the most important group in the Carboniferous system, it is everywhere of less geological interest than those above and below. These measures attain their greatest development in North Staffordshire,

where they are no less than 4,000 feet thick, with forty coal-seams and eleven beds of ironstone. In Lancashire the total thickness is nearly as much, but the workable coals are fewer. In South Yorkshire there are again about forty-eight coal-seams, the lowest being the "Silkstone" or Sheffield coal, which is the same as the "Arley mine" of Lancashire. The fossils are plants, fishes, and fresh-water shells.

**Upper Coal-Measures.**—These measures vary greatly in composition, and the coals they contain are generally too thin to be worked. They are chiefly found on the western side of the Pennine axis in Staffordshire and Lancashire, though an equal thickness may exist on the eastern side beneath the overlapping Permian rocks. In North Stafford they consist of red and purple mottled clays with brown sandstones, greenish conglomerates, thin coals, and a bed of Spirorbis limestone. Near Manchester they exhibit the following interesting succession:—

| | Feet. |
|---|---|
| Reddish clays, shales, and sandstones, with six beds of grey limestone, two thin coal-seams, and a band of hæmatite . . . . . | 600 |
| Red and grey clays, shales, and flagstones . . | 600 |
| Grey and black shales and sandstone, with six coal-seams . . . . . | 710 |
| | 1,910 |

As regards their presence in the eastern coalfield, it is not unlikely that the beds pierced by the deep boring at Scarle, near Lincoln, belong to this stage. They were entered at a depth of 1,900 feet, and consist of grey shale and limestone (118 feet), greenish grit and breccia (1 foot), and red clay (10 feet).

Again, near Rotherham in South Yorkshire there is a massive red sandstone, which was formerly considered to be of Permian age, but which is now referred to the Carboniferous. Of this Professor A. H. Green remarks:—"It is in favour of the Coal-measure age of the rock that measures can be seen directly overlying it which cannot be distinguished from the ordinary shales and sandstones of

the Coal-measures, and which contain seams of coal." At the same time there is evidence to show that it is decidedly unconformable to the main mass of the Coal-measures. It may, therefore, be provisionally referred to an upper division of the Coal-measures resting unconformably on the main body of that formation, and it is very likely analogous to the Whitehaven sandstone of the Cumberland coalfield, and the upper unconformable division of the Ayrshire Coal-measures (see pp. 201 and 207).

### 5. North Pennine Area.

As already mentioned (p. 192) the Lower Carboniferous rocks extend northward uninterruptedly through the moorland district of West Yorkshire, Westmoreland, and Northumberland to the Cheviot Hills and the shores of Berwick, supporting on their eastern flanks the great coalfields of Durham and Newcastle. The western boundary of this great Carboniferous tract is the important dislocation known as the Pennine fault, which commences at Brough in Westmoreland, and runs in a N.N.W. direction by Cross Fell to the borders of Dumfries, a distance of about 50 miles. To this fault is due the great escarpment which bounds the eastern side of the Eden valley, and the amount of vertical upthrow along this line is in some places as much as 6,000 feet.

**Tuedian Series.**—These beds are so named from their development in the Tweed district; they consist of yellow sandstones, purple shales, greenish sandy clays (sometimes full of hard siliceous concretions), and thin bands of hard cream-coloured limestone or cement-stone; near the Cheviot hills, however, sandstones predominate, and pass laterally into red conglomerates containing rolled pebbles of the Cheviot porphyrites, these fragments increasing in size as the parent masses are approached.

The Tuedian beds are estimated at about 2,000 feet, and they are now regarded as representing the lowest part of the Carboniferous Limestone of Yorkshire.

**Bernician Series.**—This includes the representatives of the Upper Carboniferous Limestone and Yoredale Beds of

Yorkshire. In the north of that county these two series are still distinguishable as separate stages, yet as they are followed northwards they lose their typical characteristics, and merge into one great series of alternating limestones, shales, and sandstones, with many workable beds of coal. The lower part of this Bernician series is of course homotaxial with the Limestone group, and the upper part with the Yoredale group, but there does not appear to be any well-marked or persistent bed which would serve as a line of division between them. Beds of this type stretch northward from Hexham and Haltwhistle to the borders of the Cheviots and north-eastward to the sea, forming the coast-line from Alnmouth to Berwick-on-Tweed.

In the Cross Fell and Alston district on the borders of Durham the thickness of the series is not more than 2,500 feet, of which 1,500 may be referred to the Lower Bernician and 1,000 to the Upper Bernician (Yoredales); it includes some twenty different beds of limestone, eight being placed in the upper stage, and the remainder in the lower. Six of the Yoredale limestones can be followed all across the county, but the lower limestones appear to be less persistent, and have not yet been correlated with those seen along the coast section.

The most remarkable point in the Northumberland series is the great development of the mechanical sediments in the centre of the county: at Alston, between the "Felltop" and "Little" limestones, there is about 350 feet of shales and sandstones; in the Inghoe district north of the Tyne this interval has increased to 1,450 feet, with three intercalated beds of limestone. Here the total thickness of the Bernician group is estimated at 8,000 feet, but eastward it again diminishes, and along the coast it is once more reduced to between 2,000 and 3,000 feet.

In the north of the county the series includes seventeen workable seams of coal, and there are about the same number in the south. Three principal groups of grits are recognized in the following descending order: (1) Inghoe Grits, (2) Simonside Grits, (3) Harbottle Grits; these, however, are not continuous groups, but only local lenticular developments of the gritty members of the series. The Harbottle Grits lie at its base, and have been classed

by some in the Tuedian series because they contain the fossil *Anodonta Jukesii*, which is only elsewhere found in the basement "Yellow Sandstone" of Ireland. In the Berwick district the Dun limestone of Lamberton is arbitrarily taken as the base of the group, but this is probably above the horizon of the Harbottle Grits.[1] (See p. 208.)

**Millstone Grit.**—This division is thickest in the south, the usual grit series being found in the vicinity of Teesdale; but as the group is followed northward its thickness rapidly diminishes, till in Durham and Northumberland the whole is only between 300 and 400 feet, if the Felltop limestone is rightly taken as the upper limit of the Bernician series.

**The Gannister Series** shows a similar attenuation. In the South Yorkshire coalfield, about Bradford and Halifax, they are more than 1,000 feet thick, with eight or nine seams of coal, but when found again in Durham they are not more than 150 feet thick, with a few thin coals. They pass down into the Millstone Grit, so that the whole thickness between the Felltop limestone and the Brockwell coal (which is the lowest workable seam) is not more than 500 feet.

**The Coal-Measures** of Durham and Newcastle probably represent the Middle Division only, for though Professor Hull separates the upper 900 feet, containing thick beds of sandstone or "post," as an upper series, yet they do not seem comparable with the red and green rocks of the true Upper Coal-measures elsewhere. The full thickness of the Northumberland measures is about 2,000 feet, and they contain some twenty good seams of coal, including the Brockwell seam at the base, and the Closing Hill seam, which is the highest known seam in the series. Besides these there are many minor or less valuable seams, bringing the total number to over sixty. Some of the shales contain nodules and bands of ironstone which have occasionally been worked, and some of these are so full of *Anthracosia* shells that they are known as "Mussel bands." The sandstones are used for building purposes, and one bed, known locally as the "grindstone post," furnishes the celebrated Newcastle grindstones.

[1] Lebour's "Geology of Northumberland."

### 6. The Lake District, and Isle of Man.

This district includes the extreme north of Lancashire, with parts of Westmoreland and Cumberland, the central region consisting of the high ground formed of the Ordovician and Silurian rocks (see fig. 13, p. 96). The Carboniferous rocks enclose this tract on every side, except on the east for a distance of about twenty miles between Egremont and the Duddon estuary, where they are overlapped by the Permian. They occupy a small area in the south of the Isle of Man.

**Carboniferous Conglomerate (Tuedian).**—In the Ulverston and Lindale district the Carboniferous Limestone seems to be everywhere faulted against the older rocks, but near Kirkby Lonsdale a remarkable conglomerate is found at the base resting on Coniston Grits, and containing large angular boulders of the older Palæozoic rocks; on some of these blocks Professor Ramsay detected scratches which he refers to the agency of ice. Their thickness is between 200 and 300 feet, and they are succeeded by shales and limestones.

Similar beds are also exposed in the banks of the river Rawthey and its tributaries near Sedbergh, and are visible at several places along the northern border from Killeth by Shap Wells in Birkbeck, Bampton, Ullswater, &c. In Cumberland they form the mass of Mell Fell, and are well exposed in the banks of Dacre Beck. Between the localities above named they are overlapped by the Carboniferous Limestone, and they seem to occupy the hollows of ancient valleys and fiords excavated in the Silurian rocks during the time that these formed part of the Old Red Sandstone continent.

In the Isle of Man coarse brecciated conglomerates surround the Castletown basin, except at Peel, where there are red sandstones with thin cornstones like the lower part of the Calciferous group of Scotland. *Orthis Sharpei* and other Carboniferous fossils occur in a calcareous part of the breccia.

**Carboniferous Limestone.**—This forms a continuous

strip along the northern border of the Lake District commencing near Egremont, and running by Cockermouth, Treby, Hesket, Shap, and Orton, to Ravenstonedale; southward it spreads out over a large tract in the Kendal district, and also along the northern shores of Morecambe Bay to Ulverston and Millom across the Duddon. The lowest beds are sandstones, shales, and limestones in alternating succession; the middle portion consists of massive limestones, and the upper part of limestone and shale. In the north-east these beds dip below the Permians of the Eden valley, but are brought up again by the great Pennine fault already mentioned.

In the Isle of Man the limestone series is divisible into three groups:[1] 1, a lower group, weathering to a yellowish brown; 2, a middle group of massive white limestones; 3, an upper group of black limestones and shales, with black calcareous flagstones and beds of volcanic ash; these contain *Posidonomya Becheri* and *P. literalis*, and other marine fossils associated with ferns and Calamites. It is clearly identical with the black limestone group of Flintshire. No higher beds occur in the island.

**Millstone Grit.**—The grits and shales, with thin coals, at Hesket Newmarket probably belong to this division, and they are succeeded by the *Lower Coal-Measures*, which form a long strip running from Maryport to Welton, and are also brought up by faults between Harrington and the hills north of Moresby. They contain only thin coal-seams of inferior quality.

**Middle Coal-Measures.**—These are represented by measures over 1,000 feet thick, containing seven workable coal-seams at Workington. At Whitehaven the same measures are covered by massive red sandstones formerly referred to the Permian, but now regarded as Carboniferous, and probably corresponding with the Rotherham rock of Yorkshire.

### 7. Scotland.

The Carboniferous rocks of Scotland lie mainly in the wide lowland tract which intervenes between the northern

[1] "Geology of the Isle of Man," by J. Horne, "Trans. Edin. Geol. Soc.," vol. ii. part iii.

and southern highlands, and is drained by the rivers Forth and Clyde. Their northern boundary line leaves the Clyde near Dumbarton, and passes north-eastward by Stirling, Kinross, and Cupar, to St. Andrew's Bay in Fife; the southern boundary ranges in a parallel direction from Girvan in Ayrshire to Dunbar in Haddington.

The following table, for which I am indebted to Mr. Hugh Miller, gives the complete succession of the Carboniferous system in Scotland, as worked out by the Geological Survey, with their probable equivalents in North England:—

*Classification of Scottish Carboniferous Rocks with their English equivalents.*

| Scotland. | | Thickness. | Northumberland. |
|---|---|---|---|
| Upper or Red Coal-Measures | | 200-300 | [Wanting.] |
| [Gentle unconformity.] | | | |
| Lower Coal-Measures | | 1100 | Lower Coal-Measures. |
| Millstone Grit Series | | 90-600 | Millstone Grit. |
| Carboniferous Limestone Series. | Upper or Limestone Group | 600-1000 | Greater part of the Upper Limestone Series (see p. 208). |
| | Middle Coal and Ironstone Group ("Edge Coals") | 400-600 | |
| | Lower or Limestone Group | 200-400 | |
| Calciferous Sandstone Series. | Upper or Cement-stone Group. (Very variable.) | 2000-3000 | Lowest part of the Upper Limestone Series; with the Lower Limestone Series, including the Basement Beds. |
| | Lower or Red Sandstone Group. (Very variable.) | 50-2000 | |

**Carboniferous Limestone Series.**—The Scottish equivalents of this series present a totally different aspect from the Derbyshire, and even from the Bernician beds. The series is divisible into five well-marked groups in the following order:—

5. Upper Limestone group,
4. Edge Coal group,
3. Lower Limestone group,
2. Cement-stone group,
1. Red Sandstone group.

1. *Red Sandstone Group.*—As already mentioned, there is no good stratigraphical base to the Scottish Carboniferous system. In Berwick and East Lothian the Geological Survey have referred the lower and redder portion of the basement series to the Upper Old Red, and consider the Carboniferous system to begin where grey and white sandstones first come in; but it is very probable that all the so-called Upper Old Red in Berwick and Haddington is of Carboniferous age,[1] and in later memoirs on other districts a red sandstone group is admitted below the Cement-stone group.

In the Pentland district the Liberton conglomerate lies at the base of the system (see p. 153), and at Kipp's Hill similar conglomerates are interstratified with red sandstones and a seam of cornstone, and overlain by pale reddish white sandstones, with beds of reddish and grey clay or marl.

In Lanarkshire,[2] "It is interesting to observe that where the Carboniferous rocks rest upon the Old Red Sandstone (*i.e.*, Lower Old Red Sandstone), their lowest beds consist of conglomerate made up from the waste of the older formation, and that these conglomerates continue to fringe the Carboniferous area, while the strata above pass quite away. Hence, in this continuous band of conglomerate, one portion is on the horizon of a low part of the Calciferous Sandstone series, while another portion is on the horizon of some of the higher members of the Carboniferous Limestone series. It thus brings before us evidence of shore conditions during a protracted submergence of this area in Lower Carboniferous times."

In Renfrew, Ayr, and Arran red sandstones and conglomerates are largely developed at the base of the Carboniferous system, and are more than 1,500 feet thick, as described in the following quotation:—

"The basement group of red sandstones is well developed at Ardrossan and along the western slopes of the hills to the north of that seaport. Although red or reddish grey sandstone is the prevailing rock, conglomerate bands

[1] These beds lap round the flanks of the Lammermuir Hills, and are from 1,500 to 2,000 feet thick (see p. 152).

[2] "Mem. Geol. Surv. of Scotland, Expl. of Sh. 15," p. 30.

also occur, particularly as the rocks are followed towards the north. In these conglomerates the prevalent pebbles are white quartz, and as both the number and size of these pebbles increase towards the north, there can be little doubt that they have been derived from the waste of the Highland metamorphic rocks. The sandstone group extends northward through Renfrewshire; it is found likewise in Bute, and it forms the basement group of the southern half of the island of Arran, besides stretching as a narrow strip along the eastern margin of the northern half of the island. Its thickness cannot be accurately ascertained, its base being concealed by the Firth of Clyde; but from the base of Kaim Hill to the sea-margin at Fairlie, it cannot be less than 1,500 feet."[1]

At Corrie, in Arran, a band of marine limestone, crowded with shells of Carboniferous Limestone species, has been discovered deep down in this Red Sandstone series. Hence it is evident that the marine Carboniferous fauna was already in existence outside the area where conditions continued to favour the formation of red sandstones, and that to separate these sandstones from the Carboniferous system would be contrary to direct palæontological evidence. It is seldom, as Dr. Geikie remarks, that we obtain such clear evidence of the palæontological relations between formations of such widely different lithological types, making it certain that the Carboniferous fauna was establishing itself at this early period outside the Arran area, and was ready to spread over it as soon as conditions became favourable to the invasion.

The Carboniferous rocks of the Thornhill Basin in Ayrshire consist of the following series:—

3. Sandstones, red, grey, and white, with red and purple shales.
2. Red limestone bands, with Carboniferous limestone fossils.
1. Red and reddish grey sandstones and shales.

These are regarded as of Lower Calciferous Sandstone age; at Closeburn there is a red magnesian limestone fourteen feet thick, a fact which connects them with the Corrie

[1] "Mem. Geol. Survey of Scotland, Expl. of Sheet 22," p. 13.

series of Arran, for there too a red magnesian limestone is found above the fossiliferous limestone.

2. *Cement-stone Group.*—This is the upper stage of the Calciferous Sandstone series of Scottish geologists, but is admitted by Dr. A. Geikie to be the equivalent of the lower part of the English Carboniferous Limestone. It consists of light-coloured sandstones, dark shales, thin limestones, and a few thin seams of coal. It is essentially a freshwater series, the principal fossils being plants, fish, and freshwater crustacea (Cyprids), but marine bands occur occasionally containing *Discina nitida*, *Lingula squamiformis*, *Orthoceras cylindraceum*, &c. In Berwickshire the lowest marls and sandstones contain *Lepidodendron Veltheimianum*, *Cyclopteris flabellata*, and other plants. The limestones in the lower part of the group are the compact cherty beds known as "cement-stones" in Midlothian. In the middle of the group is a more important bed, the Burdiehouse limestone, which is of very variable thickness, sometimes swelling out to 40 feet or 70 feet, and elsewhere thinning down to a few calcareous bands, with intervening shales; in many places it is chiefly composed of the small bivalved crustacean *Leperditia Okeni*, but contains many other fossils, notably the fish *Rhizodus Hibberti* and *Eurynotus crenatus*, and the plants *Sphenopteris affinis*, *Lepidodendron* (and *Lepidostrobus*) *variabilis*. Some of the black shales associated with this limestone are of the kind known as "oil shale," and yield from thirty to forty gallons of petroleum per ton; I am informed, indeed, by Mr. H. M. Cadell, of the Geological Survey, that some of these shales have yielded as much as eighty gallons per ton, besides a considerable quantity of sulphate of ammonia as a by-product. The shales now sought after are poorer in oil but richer in ammonia, some of the Pumpherton shales yielding as much as 60 or even 80 lbs. per ton. In Midlothian the Cement-stone group cannot be less than 2,000 feet thick.

3. *Lower Limestone Group.*—Near Edinburgh this group has a thickness of 400 feet to 500 feet, and contains three beds of limestone, but these are seldom more than 12 feet thick, though occasionally swelling out to 30 feet, and in the Bathgate Hills (Linlithgow) to 70 or 80 feet. In Ayrshire the Hurlet, or Main Limestone, attains a thickness

of 100 feet. *Spirifer trigonalis*, *Productus giganteus*, and *P. semireticulatus* are common fossils, and in some places the limestones are largely composed of the shelly plates forming the arms and stems of Crinoids. These limestones are interbedded with a series of shales, sandstones, and coal-seams, several of the coals being immediately succeeded by a limestone, *e.g.*, the Hurlet coal and limestone, as if there had been times when the shallow lagoons and swamps were suddenly submerged and occupied by marine organisms.

4. *Edge Coal Group.*—This is a shale and sandstone series, and it includes some valuable seams of coal, ironstone, and oil-shale, but no limestones. In Midlothian its thickness is 600 feet. Some of the beds contain marine shells, others are full of terrestrial plants, showing that the gradual submergence which was in progress was now and then counterbalanced by the deposition of the sediment brought down in such quantity by rivers.

5. *Upper Limestone Group.*—This is also about 600 feet in Midlothian ; it contains three bands of limestone and four seams of coal, interstratified with sandstone, shale, and fireclay. The limestones contain the same fossils as those of the lower group, and though seldom more than three or four feet thick, have been traced over an area of at least 1,000 square miles ; thus proving to us that the physical conditions of the period were very uniform over very large areas.

**Moorstone Rock.**—In the counties of Edinburgh, Fife, and Lanark, the Garnkirk limestone (which is the uppermost of the limestone bands above mentioned) is succeeded by a series of thick-bedded pale red and yellow sandstones, with interbeddings of shale. These beds have also been termed the Roslin Sandstone, and correspond to the Millstone Grit of England. Westward, in Ayrshire, they are so reduced in thickness as not to be definitely separable.

**Coal-Measures.**—The measures above the horizon of the Moorstone rock attain their greatest development in the basin of the Clyde, where they are about 1,300 feet thick ; in Fifeshire their thickness is much less, but in Midlothian they are again about 1,200 feet thick. I am

informed by Mr. B. N. Peach, of the Geological Survey, that the mass of the Scottish Coal-measures contains a flora which is identical with that of the Lower Coal-measures of Northern England, and that the Middle Coal-measures appear to be absent in Scotland. The series consists of grey and white sandstones, with shales, coals, fireclays, and ironstones, ten of the coal-seams being over two feet thick. The Upper Coal-measures consist chiefly of red sandstones and clays, with a band of "Spirorbis" limestone in Ayrshire; they are slightly unconformable to the lower measures, and overlap them so as to rest upon the Lower Limestone series, a fact which may account for the absence of the Middle Coal-measures.

[While these pages were passing through the press I became aware of the conclusions arrived at by those of my colleagues who had surveyed the Carboniferous districts of Northumberland, and who found that the classification of the Carboniferous Limestone series proposed by George Tate[1] in 1863 was applicable to the whole Northumbrian area, and conveyed a better idea of the succession than that proposed by Professor Lebour at a later date.[2] Had I been previously aware of this, I should not have introduced the term Bernician into the text.

The following is the modification of Tate's classification which is recognized by the members of the Geological Survey as applicable to the Northumbrian type of the series:—

[1] "Trans. Tyneside Field Club for 1863."

[2] Consult Hugh Miller in "Encyclopædia Britannica" (9th edition), article "Northumberland."

NORTHUMBRIAN TYPE OF THE CARBONIFEROUS LIMESTONE SERIES.

| | Divisions. | Thickness in feet. |
|---|---|---|
| Upper Limestone Series. | *Fell-top division* (between the Millstone Grit and the zone of the Great Limestone). Sandstones and shales, with some coals, and one or more beds of marine limestone . . . . | 350-1,200 |
| | *Calcareous division* (from Great Limestone to base of Dun or Redesdale Limestone). Sandstones and shales, with coals, and many beds of marine limestone . . . . . | 1,300-2,500 |
| Lower Limestone Series | *Carbonaceous division* (Scremerston Beds). Strata prevalently carbonaceous; limestones chiefly thin, many of them containing carbonaceous matter; coals . . . . . | 800-2,500 |
| | *Tuedian division.* | |
| | *b.* Upper Tuedian or Fell Sandstone group (Tweedmouth, Simonside, Harbottle, and Bewcastle Fells): a belt of massive grits with green, grey, and reddish shales; coals rare and thin . . . . . | 500-1,600 |
| | *a.* Lower Tuedian or Cementstone group: sandstones and shales, with bands of cementstone passing into limestones near Rothbury and Bewcastle | 500-1,500 |
| | Basement conglomerates (Upper Old Red Sandstone) . . . | 0- 500 |

Mr. Hugh Miller informs me that the base of the Carbonaceous division is not everywhere well defined, otherwise the whole series might be made into three divisions, the two upper being grouped as one division.]

## 8. Ireland.

In no country can the rocks of the Carboniferous system be better studied than in Ireland. They occupy fully one-half of the superficial area of the country, the whole of the great central plain, which stretches completely across the island from east to west, consisting of the Carboniferous Limestone, though its surface is often covered by Pleistocene gravels. The lower groups of the system emerge from beneath the limestone to the north and south, while here and there the limestone plain supports hills of low elevation composed of the Coal-measures; these outliers are the sole remnants of the beds which once spread over the limestone, and their survival is due to the circumstance of their lying in synclinal troughs or basins; "like solitary columns amidst the ruins of ancient temples, they are monuments of the decay and waste which has reigned around."[1]

**Northern Counties.**—Just as the Scotch Cambrian and Silurian rocks strike south-westerly into the north of Ireland, so also do rocks of the Scotch Carboniferous type. A series similar to that of Ayrshire is found near Ballycastle, in Antrim, and consists of the following groups:—

| | | Feet. |
|---|---|---|
| Edge Coal Series. | Reddish and grey sandstones, with seams of coal and black-band ironstone . . . . . | 240 |
| Limestone Series. | Calcareous shales, with two beds of compact argillaceous limestone . | 55 |
| Cement-stone Group. | Red and yellow sandstones, with beds of shale and a quartzose conglomerate at the base, resting upon mica-schist . . . . . | 1,000 |

The diminished thickness of the Limestone series is worthy of note, especially as, when the Carboniferous rocks are again seen in Tyrone to the south-west, the Carboni-

[1] Hull, "Physical Geology of Ireland," p. 153.

ferous Limestone has a massive development, and the whole series there exposed resembles the more normal type of central England. The succession in Tyrone, Fermanagh, and Leitrim may be summarized as follows:—

| | Feet. |
|---|---|
| 6. Middle Coal-measures, with good coal-seams | 930 |
| 5. Gannister Measures, grits and shales, with a few coal-seams and ironstones | 1,000 |
| 4. Millstone Grit, coarse quartzose grits | 200 |
| 3. Yoredale Beds, black shales and thin limestones | 600 |
| 2. Carboniferous Limestone, in three stages | 2,600 |
| 1. Yellow Sandstone | 500 |
| Base not seen | |
| | 5,830 |

The great Limestone Series (No. 2) is divisible into four stages—1, the upper limestone with nodules of chert, 500 feet; 2, the Calp Series, composed of carbonaceous shales ("calp") with earthy limestones and a central bed of sandstone, 1,200 feet; 3, the Lower Limestone, compact and often dolomitic, 800 feet; 4, the Lower Limestone Shale, 100 feet, which graduates by alternations of shale and sandstone into the basement beds (Yellow Sandstone).

The Tyrone coalfield is the most important in Ireland, and contains twenty-four coal-seams, of which ten are now worked.

**Central Plain.**—The Carboniferous Limestone emerging from beneath the higher measures stretches southward in gentle undulations over the vast tract of country which forms the central plain of Ireland. At the same time the group exhibits a lithological change similar to that observable in England, namely, a diminution of the mechanical sediments and an increase of calcareous matter as it is followed southward, till in Clare, Tipperary, and Queen's County it becomes a solid mass of limestone, estimated at more than 3,000 feet in thickness. This is one of the largest limestone aggregates to be found anywhere in the world; its

general character is a compact fine-grained grey limestone, sometimes dark, sometimes light grey, sometimes mottled with red streaks or bands, the beds so marked being quarried for ornamental marbles.

In the hills of Burren, co. Clare, the upper part of the limestone is magnificently developed, and is thus described by Mr. Jukes:[1]—

"A range of hills, rather more than a thousand feet in height, sweep for about twenty miles along the south side of Galway Bay. They are formed entirely of bare rock from the sea-level to the hill-tops, the only soil being found in crevices of the rock, or in patches in the hollows of the valleys. This rock is all limestone, in regular beds, which dip gently to the south, at an angle of $1\frac{1}{2}$ degrees only, and counting from the lowest bed that rises out on the sea-shore to the uppermost, which caps the summit of the hills three or four miles to the southward, there must be a thickness of at least 1,600 to 1,700 feet of solid limestone shown here.

"Terraces of twenty yards in breadth have been worn here and there on the top of some particular bed, and may be walked along for many miles round the sides of the hills and valleys, which resemble great stairs or vast amphitheatres. They are not, however, very easy to traverse, since the rocks are so cut by several systems of joints, and those joints are so worn and opened by the action of weather, that each exposed bed is cut into blocks by deep fissures, and the uppermost blocks are often loose and tottering, and worn into rough knobs and holes by the mechanical and chemical action of the weather.

"The upper part of the limestone thus admirably exposed in this hill country forms probably about half the whole formation, the lower portion spreading to the east over a low country, from beneath which the Old Red Sandstone rises gently out on to the hills called Slieve Boughta."

According to Mr. Kinahan, the upper limestones include two cherty zones, and represent both the upper limestone and the Calp series of Ulster, and the limestone below is characterized by an abundance of *Fenestella flabellata*. He gives the succession as follows:—

[1] "Manual of Geology," second edition, p. 512.

| | | Feet. |
|---|---|---|
| Upper Limestone. | Bedded limestone, with chert layers | 1,500 |
| | Cherty zone | 40 |
| | Black limestone and shale, with a cherty zone | 400 |
| Lower Limestone group. | Fenestella limestone | 300 |
| | Lower cherty zone | 100 |
| | Lower shaly limestones | 400 |
| | Lower limestone shale | 150 |
| O. R. S. | Basal sandstones | 1,000 |
| | | 3,890 |

This great mass of limestone supports outlying tracts of the Upper Carboniferous groups in Leinster and in Clare, the general section of these being as follows (see fig. 43):—

Upper Coal-measures (absent in Leinster).
Middle Coal-measures (700-800 feet).
Lower Coal-measures (500-900 feet).
Flagstone group, Millstone Grit (70-200 feet).
Yoredale Shales (about 500 feet).

**South Counties.**—As above mentioned, the lowermost beds again emerge from beneath the limestone towards the south in the counties of Tipperary, Waterford, and Kilkenny. They consist in descending order of dark shales

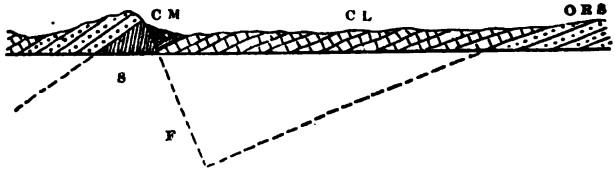



Fig. 42. Section through part of Tipperary.

CM. Coal-measures. ORS. Red and Yellow Sandstones.
CL. Carb. Limestone. S. Silurian.
F. Slievenamuck Fault.

which pass downward by alternation into beds of yellow and greenish sandstone (just as in South Wales). At

Fig. 43. Section across the Leinster Coalfield (Professor Hull). Distance 22 miles.

*f*. Middle Coal-measures.
*e*. Lower Coal-measures.
*d*. Flagstone Group.
*c*. Yoredale Shales and Upper Limestones.
*b*. Middle Limestone.
*a*. Lower Limestone.
g. Granite of Carlow.

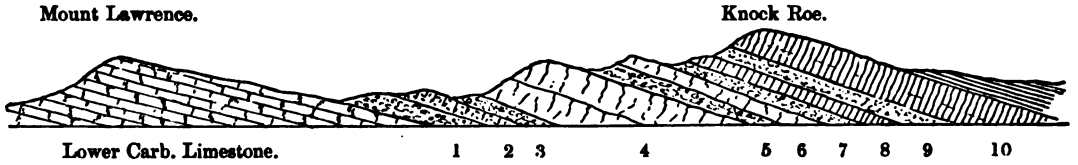



Fig. 44. Section through part of the Volcanic Series of Limerick (Professor Hull).

1. Ashes and lapilli.
2. Basalt (possibly intrusive).
3. Ashes.
4. Felstone.
5. Ash.
6. Felstone.
7. Ash.
8. Felstone.
9. Ash.
10. Columnar Felstone, with crystals of augite.

Kiltorcan Hill, in Kilkenny, these yellow sandstones have yielded fine impressions of ferns and other fossils; they are followed conformably by red sandstones and shales like the Upper Old Red Sandstone of Wales, which rest unconformably upon the older (Silurian) rocks; see fig. 42, which shows the repetition of the whole series by the great Slievenamuck fault. These beds were described on p. 160, but are in all probability the basement beds of the Carboniferous system.

When the Carboniferous rocks are traced to the south-west through Cork and Kerry a still greater and much more sudden change takes place in the constitution of the system. This consists in the introduction of what appears to be a distinct group of shales and slates between the Yellow Sandstone and the Carboniferous Limestone, and to which Sir R. Griffith gave the name of *Carboniferous Slate.* This group of beds has derived special importance from its bearing on the Devonian question, and the whole subject is so associated with the name of Jukes, that it would be idle to attempt a better exposition of the interest attaching to the Carboniferous Slate than is contained in Mr. Jukes' own description quoted below.[1]

"If we draw a parallel of latitude through the towns of Kenmare, Macroom, and Cork, the great development of Carboniferous Slate lies wholly south of that line. If we examine the neighbourhood of the city of Cork itself, we find the Old Red Sandstone with plants in its upper beds, and a very short distance above that we get solid Carboniferous limestone, with some black shales or slates between the two, but not more than 200 or 300 feet in thickness. Passing southwards to the mouth of the harbour of Monkstown or Queenstown, and then by Carrigaline and Coolmore, these intermediate black slates or shales thicken to 2,000 or 3,000 feet, still having the Old Red below and the Carboniferous limestone above; but going still further south by Ringabella to Kinsale, the dark grey slates and grey grits thicken rapidly to 5,000 or 6,000 feet, and are nowhere covered by any part of the Carboniferous limestone, though they show here and there highly calcareous bands.

[1] "Manual of Geology," second edition, p. 510.

"The whole of the rocks are thrown into numerous anticlinal and synclinal curves, over many interrupted axes which strike very steadily from E.N.E. to W.S.W.; and the headlands and bays along the south coast of Cork exhibit numerous transverse sections across the beds, so that no mistake can be made respecting the facts. On tracing the beds round the entrance of Bantry Bay, and into the trough of Kenmare Bay, we find the Carboniferous Slate in the hollow of the synclinal as far as Sneem and Clonee. Beyond these points, however, the beds of [Old] Red Sandstone, which dip beneath the waters of the bay from each side, seem to close more together and exclude the Carboniferous Slate, and when the head of the bay is reached, the flat land is composed of solid limestone, with a thickness of not more than one hundred feet of shales and grits between the base of the Carboniferous Limestone and the top of the Old Red Sandstone."

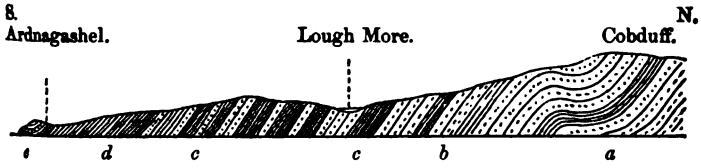



Fig. 45. Section near Glengariff (Jukes). Distance about 2½ miles.

| | |
|---|---|
| *e*. Black slates with calcareous bands. | |
| *d*. Black and grey slates. | Carboniferous Slate. |
| *c*. Coomhola grits, greenish-grey grits with black and grey slates; marine fossils. | |
| *b*. Greenish-grey grits with green and purple slates, and occasional cornstones; the only fossils are fragments of plants. | Glengariff Grit Series. |
| *a*. Glengariff grits, massive green and purple grits, with thin bands of purple slate. | |

Kenmare is not more than ten miles from Glengariff, so that within that distance the series changes from the type shown in fig. 42 to that illustrated by fig. 45.

Now the question naturally arises,—what part of the Carboniferous series do these slates and grits represent? Although they appear to fit in wedgewise between the Yellow Sandstone and the Carboniferous Limestone, yet the

probability is that they correspond to much more than the Lower Limestone Shale. At Whiddy Island, at the head of Bantry Bay, there are black shales containing *Posidonomya Becheri* and *P. membranacea*, the characteristic species of the Yoredale Beds, and it is therefore highly probable that the Carboniferous Slate is absolutely contemporaneous with the whole of the Carboniferous Limestone, the lower and upper parts of that formation passing laterally into shales just as its middle part does to the northward. We may therefore regard the Carboniferous Slate as representing the whole of this limestone and its underlying shale, or strata amounting to a thickness of 2,600 feet in the northern part of Ireland; such in fact was Mr. Jukes' opinion.

This will partly account for the small thickness of shale at Kenmare, the limestone there replacing the higher beds of shale. Professor Hull, however, believes that this rapid thinning out is mainly due to the proximity of a coast-line, and maintains that the Carboniferous Slate has here overlapped the Coomhola Grit group and the Upper Old Red Sandstone so as to rest directly upon the Glengariff Grit series.

### 9. Devonshire.

This area has been left till the last because Mr. Jukes always maintained that the key to the complicated structure of Devonshire was to be found in the south of Ireland, and that the comparative age of the Devonian rocks could only be ascertained by the light of experience gained in Cork and Kerry. In this he was doubtless correct, and though the actual hypothesis which he proposed to explain the structure of North Devon may not seem warranted by the facts so far as they are at present known, yet he was certainly able to identify some of the Devonian rocks with the Irish strata, and thus to indicate their true place in the geological scale, detaching them from the Devonian system, with which they had previously been grouped.

The Carboniferous Series of Devonshire may be summarized and correlated as follows:—

| Devon. | Ireland. | Bristol. |
|---|---|---|
| Upper Culm-Measures. | Lower C. M. | Lower C. M. |
| Middle " " | Millstone Grit. | Millstone Grit. |
| Lower " " | Upper Limestone and Calp Shales. | Upper Limestone and Shales. |
| Pilton and Barnstaple Beds. | Lower Limestone and Carb. Slate. | Lower Limestone and Shale. |
| Baggy and Marwood Beds. | Coomhola Grits. | Upper O.R.S (part). |

**The Baggy Beds** consist of green slates in which a species of *Lingula* is the commonest fossil and brown micaceous sandstones containing *Cucullæa Hardingii*. The junction of the green slates with the red slates of the Pickwell Down beds may be seen on the coast. The brown (Marwood) sandstones are sometimes called the *Cucullæa* zone, but Mr. Ussher[1] states that the green slates are the more persistent stratigraphical horizon. *Lepidodendron* and *Calamites* have been found in the sandstone at Sloly, with *Lingula mola* and *Avicula Damnoniensis*.

**The Pilton Group** consists of bluish grey slates with thin seams of calcareous matter and thick beds of grit or sandstone at several horizons. These beds extend through the towns of Croydon, Braunton, Pilton, Barnstaple, and Dulverton; they contain, amongst other fossils, *Phacops latifrons*, *Spirifera Barumensis*, *Strophalosia caperata*, *Aviculopecten sp.* They pass upwards into the Culm-measures so completely that the line of division must be purely palæontological. In South Devon and Cornwall they appear to be absent, and the Culm-measures are said to rest unconformably on the red slates of the Upper Devonian.

**Lower Culm-Measures.**—These consist of black shales with lenticular beds of black limestone in the upper part. These beds seem to correspond with the black limestone and shale group of North Wales, and consequently to the Yoredale Beds of other districts. The commonest fossils are *Posidonomya Becheri* and *Goniatites* (*G. crenistria* and *mixolobus*). In the lower shales of Waddon Barton, near Chudleigh, some interesting fossils have lately been found by Mr. J. E. Lee;[2] they include the above with

[1] "Geol. Mag.," Dec. 2, vol. viii. p. 446.
[2] H. Woodward in "Geol. Mag.," Dec. 3, vol. i. p. 538.

*Orthoceras striolatum, Chonetes restispina, Spirifera Urii, Avicula lepida,* and four new species of the genus Phillipsia. Dr. Woodward notices the similarity of this fauna to that of the Culm-measures of Herborn near Dillenberg.

**Middle Culm-Measures,** or Coddon Hill series.—This consists of grey and black shales and coarse carbonaceous grits with seams of chert, the whole about 1,500 feet thick, and probably including the representative of the Millstone Grit. Near Chudleigh, Sedgwick and Murchison noticed coarse grits passing into a fine conglomerate, and overlain by thin-bedded grey sandstones.

**Upper Culm-Measures.**—This is a sandstone and shale series with beds of ironstone and culm (impure anthracitic coal. They contain Coal-measure plants and are similar to the anthracitic portion of the lower Coal-measures of Pembroke. No higher beds than these have yet been found in Devon.

### Volcanic Rocks.

**England.**—In Cornwall and Devon the lower part of the Carboniferous series contains sheets of trap and volcanic ash, similar to those which occur in the underlying Devonian series. These have not yet been carefully examined, with the exception of those in the neighbourhood of the hill called Brent Tor, near Tavistock. This well-known hill appears to be a portion of an actual volcanic cone, though the actual crater and the greater part of the cone have been demolished by repeated detrition and erosion. The present hill is about 1,100 feet high, and consists of masses of devitrified Rhyolite and Pitchstone, with some basalts and beds of volcanic breccia, the two first being evidently parts of ancient lava-flows.[1] In the country surrounding the Tor beds of schistose volcanic ash are interbedded with the Culm-measures; these were probably ejected from the volcano of the Tor, which must have been either a submarine vent or a volcanic island.

In Shropshire, near Wellington, the Carboniferous lime-

[1] Rutley, "The Rocks of Brent Tor, Mem. Geol. Surv.," and "Quart. Journ. Geol. Soc.," vol. xxxvi. p. 285.

stone rests upon a sheet of basalt which may be regarded as being of Carboniferous age.

In Staffordshire the Coal-measures are penetrated by many intrusive dykes and sheets, some of which form considerable surface areas; these intrusions are considered by Mr. Jukes to have taken place during the deposition of the Upper Coal-measures,[1] for he found ashy sandstones, *i.e.* sandstones partly formed of volcanic ejectamenta at several horizons from 400 to 900 feet above the "Thick coal;" moreover, the sheets and dykes are displaced by the faults that traverse the Coal-measures. The largest mass is the columnar basalt of the Rowley Hills, which is between 200 and 300 feet thick, and forms a plateau about two miles long by one broad, spreading out over the Coal-measures. Sheet-like masses of green trap are frequent in the underlying measures from the base of the Rowley Hills as far as Wolverhampton, Bilston, and Bentley. Barrow Hill (west of Dudley) and Pouk Hill, near Walsall, appear to be massive lenticular bosses (possibly laccolites, see vol. i., p. 414) from which the sheets intruded between the neighbouring measures have proceeded. The Titterstone Clee Hill is capped by a sheet of columnar basalt, which has preserved the outlier of Coal-measures underlying it.[2]

In Derbyshire several truly interbedded sheets of trap occur in the Carboniferous Limestone, and are locally known as *toadstones*, probably from their spotted appearance. They consist of a basalt which is sometimes dark and compact, but more often greenish, earthy, and amygdaloidal; they average 50 or 60 feet in thickness, and have been traced for many miles; they are sometimes associated with beds of green and purple ash or tuff. These lavas appear to have flowed from more than one volcanic vent, as they sometimes thicken in opposite directions.

Beds of greenish tuff and coarse ash occur in the black limestone group of the Isle of Man (see p. 201), and the centre of eruption appears to have been at the Stack of Scarlet, where there is a mass of agglomerate with a central plug of diabasic lava.

[1] "South Staff. Coalfield," second edition, p. 248.
[2] Murchison, "Siluria," fourth edition, p. 290.

**Scotland.**—The lower part of the Carboniferous system in Scotland is full of such striking instances of volcanic activity that it becomes an excellent district for the study of such phenomena. The most persistent zone of volcanic rocks, says Dr. A. Geikie, is that which succeeds the lower or red sandstone group of the Calciferous Sandstone; "great sheets of porphyrites with interbedded tuffs, sandstones and conglomerates, rise in broad masses, bed above bed, and form that conspicuous chain of terraced heights which stretches from near Stirling through the range of the Campsie, Kilpatrick, and Renfrewshire hills, to the banks of the Irvine in Ayrshire, and thence westwards by the Cumbrae Islands and Bute to the south of Arran."

In the succeeding periods of the Cement-stone and Limestone groups (see p. 205), volcanic outbursts occurred both in the western and eastern districts; Fife and the Lothians seem to have been dotted over with dozens of little volcanoes, which, either singly or in groups, ejected lavas and ashes for a time, and then became inactive, allowing other similar vents to form and take up the *role* of action, so that the district must at the time have presented an appearance like that of Auvergne; and now the Carboniferous rocks are intermingled with innumerable small sheets of basalt and tuff, and are pierced by intrusive dykes and necks filled with volcanic ash or basalt; but there are nowhere such extensive and massive sheets of lava as occur in the underlying and older groups.

In the western area, however (Ayrshire, Renfrewshire, and Dumbartonshire), the Cement-stone group is mainly composed of volcanic rocks, successive sheets of porphyrite often making aggregate masses of great thickness; extensive beds of tuff and agglomerate also occur, especially in the northern part of Ayrshire, where "the black-band ironstone appears to have been deposited in hollows between mounds and cones of volcanic tuff, sometimes 600 feet high, round and over which the later members of the Lower Carboniferous formation were deposited." [1]

In the eastern area volcanic activity continued during a still later part of the Carboniferous period.

[1] Arch. Geikie in Jukes' "Manual of Geology," p. 595; see also "Mem. Geol. Survey of Scotland, Expl. of Sheet 22," p. 16.

Many of the vents from which these tuffs and lavas were ejected can still be indicated, and Dr. A. Geikie has distinguished six different volcanic districts in the basin of the Forth, viz., (1) Haddington, (2) Edinburgh, (3) Linlithgow, (4) Stirling, (5) West Fife, (6) East Fife.

In the Haddington district many old vents occur, some filled with tuff and agglomerate, others with lava; the Bass Rock, North Berwick Law, and Traprain Law are instances. The oldest lavas are augitic, the newer are variously coloured porphyrites; interstratified tuffs and agglomerates are frequent.

The Edinburgh district includes the volcanic centres of Arthur's Seat and Craiglochart Hill. In Linlithgow there are many half-destroyed volcanic cones, and the Binns Hill is a neck or stump composed mainly of fine green tuff.

In Stirlingshire some interesting necks occur, those of the Fintry Hills having central hollows, suggestive of the original craters. Near Kilsyth the interstratified volcanic material is 1,000 feet thick, but this thins away north-eastward, and disappears near Stirling in a distance of thirteen miles.

In West Fife there are two groups of volcanic vents, one forming the Saline and Cleish Hills, the other near Burntisland. Largo Law is a very perfect example of a double cone, each composed of tuff with central pipes filled with basalt. Saline Hill has a similar structure, the whole mass resting on beds belonging to the Edge-coal group, and the outer tuffs of the cone dove-tailing into higher strata. The necks of East Fife were noticed in the first volume (p. 396).

**Ireland.**—County Limerick was the scene of powerful volcanic disturbances during the accumulation of the Carboniferous Limestone; some enormous masses of felstone, tuff, and conglomerate being included in the limestone, ejected probably from submarine vents which may sometimes have formed temporary volcanic islands. An account of these rocks has been given in the earlier volume of this work (p. 402), to which I may now add that Professor Hull distinguishes two epochs of eruption in the Limerick area, the first witnessing the extension of felspathic lavas and ashes, while the second, which occurred after a consider-

able interval, gave birth to flows of basalt and augitic lavas.

The section, fig. 44, copied by permission from Professor Hull's "Physical Geology of Ireland," illustrates the succession of materials erupted during the earlier outburst.

## Physical Geography.

The records of the Carboniferous period being more complete than those of earlier times, we possess more certain grounds on which to construct a geographical picture or map of the British Islands during its earlier stages, and can indicate with greater certainty the changes which subsequently took place.

It is clear that the period was ushered in by the breaking up and partial submergence of the great continent which included the larger part of Britain during the preceding (Devonian) period. The movement of depression appears to have extended from south-east to north-west, and the greatest amount of subsidence took place along two troughs, one coinciding roughly with the gulf in which the marine Devonians were formed, and stretching through the south of England and Wales into Ireland—the other extending through Yorkshire, Derbyshire, and Lancashire, outside North Wales into central Ireland, where its waters mingled with those of the southern gulf.

The tract of land between these two gulfs appears to have remained in the form of a large island, ridged up as it were between the two axes of depression, and extending from the Wicklow Hills in the east of Ireland across the Irish Sea, through Wales, and those parts of Shropshire, Worcester, Warwick, and Leicester, where we have seen that the Lower Carboniferous beds are entirely wanting. More or less of this island was above water during the whole of the Carboniferous period, though its eastern portion seems to have been gradually submerged during the deposition of the Upper Coal-measures.

Another island, or group of islands, existed further to the north, comprising the southern uplands of Scotland from the Cheviots westward, and probably extending south-

west into the north of Ireland. The Cambrian and Silurian rocks of the Lake District were also land in Tuedian times, though whether they formed a separate island, or were united to the other through the Isle of Man, is uncertain. Their connection with the similar rocks in the north of the Isle of Man is, at any rate, very probable; and the land may have stretched westward into the north-east of Ireland.

It is probable, however, that the whole of the Lake District and much of the southern uplands of Scotland were submerged beneath the waters of the Carboniferous Limestone Series; the basal conglomerates gradually creeping up the shores of the Cumberland mountains till they probably stretched completely across the line indicated in Mr. Goodchild's section (fig. 13, p. 96). In Berwickshire there is proof that the eastern promontory of the ancient land was thus submerged, for the red conglomerates and sandstones pass completely over the Ordovician axis, and it is evident that these deposits must once have stretched over a large part, if not the whole, of the Lammermuir chain.

The higher and central part of the Scottish uplands may, however, have remained above water until the close of Lower Carboniferous time, but it was probably entirely submerged during the formation of the Coal-measures.

The area of Lake Caledonia on the north was of course submerged, but never to any great depth, and the persistent recurrence of shallow water conditions in the Scotch Carboniferous series tempts one to speculate upon the conversion of this area into a land-locked gulf, or fiord, cut off by the ridge above mentioned from the deeper sea that lay to the southward over England and over the centre and southern part of Ireland, and only united to it by a narrow strait in the north of Ireland.

Continental land appears to have existed to the north-west, but the position of its southern coast-line cannot be indicated with any precision; we only know that it lay north of Morvern in Argyleshire, and thence bent southward to the north-west of Ireland, passing probably through Donegal and the western parts of Mayo and Galway. The further trend of this coast is uncertain, but the promontories of south-west Ireland between Brandon, Dingle, and Kenmare Bays as far east as Killarney were

above water at this time, and may have formed a rocky promontory projecting *eastward* from the main coast-line. Professor Hull considers that this was part of the coast-line of a vast continent which stretched southward from the Arctic regions and occupied the place of what is now the North Atlantic Ocean (see Frontispiece); its eastern and western boundaries touching the British Isles and North America respectively.

South-west of Ireland there were probably straits communicating with the open ocean lying to the south of this great continent, and on the other side of these straits another coast-line ran near, or perhaps through Cornwall to the north of France. The distribution of the French rocks prove that there was a large mass of land in France during Lower Carboniferous times, including all the central and northern provinces, while the extreme north-east of France, together with Belgium, formed part of the southern sea-trough already mentioned. These troughs united eastward,[1] and formed part of a sea which stretched through Germany and Poland into Russia, where there are again evidences of the close neighbourhood of land. There was land also to the north in Norway and Sweden, while on the south a more or less continuous belt of land seems to have extended eastward from France through Switzerland and Austria into the south of Russia. Thus the sea in which our Carboniferous beds were deposited was not an ocean but a land-locked sea, comparable to the Mediterranean Sea of the present day, and communicating with other seas and oceans by means of one or more narrow straits like the Straits of Gibraltar.

"This Mediterranean Sea," says Professor Green,[2] "had a fringe of shallow water around its margin, and deep depressions in its central portion. Round its edges deposits were formed, mainly of mud and sand, though every now and then calcareous animals established themselves in sufficient numbers to give rise to beds of limestone. At a certain distance from the shore all the sediment sank down to the

[1] Carboniferous limestone has been found in borings beneath Northampton, see "Quart. Journ. Geol. Soc.," vol. xl. p. 482.

[2] "The Yorkshire Coalfield," by Green and Russell, "Mem. Geol. Survey," p. 24.

bottom, and beyond this limit the water was bright and clear, and the only deposit consisted of accumulations of the hard, calcareous parts of marine animals which are now pure limestone.

"In the deep hollows the deposits of limestone reached a great thickness; over the ridges which parted the hollows it was not so thick. This will explain how it is that the Carboniferous Limestone shows such great variations in thickness at different spots. The growth of the limestone gradually filled up the deeper parts of the sea, and at last the area became as shallow throughout as it had been originally only at its edges. The mixed deposits of sandstone, shale, and impure limestone, which had at first been confined to the neighbourhood of the shore, now extended themselves over nearly the whole marine tract, and the deposition of the Yoredale rocks began (in Britain). At the same time a slow sinking of the sea-bottom set in, which allowed of these beds being piled one on the top of another to a considerable thickness.

"After a time a further important change took place. Either by the outlets becoming blocked up, or by the upheaval of a portion of the bottom, the land-locked area in which the lower marine portion of the Carboniferous rocks was deposited became cut off from communication with the open ocean on the (south) west, and converted into a freshwater lake or a large estuary which received the waters of rivers flowing from the north, east, and south. In this freshwater, or brackish area, the Millstone Grit and Coal-measures were deposited. The water was never very deep, but the subsidence which had begun in Yoredale times went on during the deposition of the beds next above, and they too, in consequence, reach a great thickness. When the water was at its shallowest, currents piled up banks of sand, or drifted coarse materials over the bottom, and shot them down into hollows, and thus formed lenticular beds of sandstone, or washed down and spread out pre-existing sandbanks, and gave rise to more regular sandstone beds. When the depth was greater, only fine mud was brought into the water, which settled down into more regularly bedded and uniform deposits of shale.

"The subsidence which allowed of the growth of the

mechanically-formed deposits did not go on without interruption. Every now and then a pause occurred, and whenever this happened, the water became filled up, and there was a tendency to the formation of low, swampy flats. Perhaps, occasionally, small upheavals helped in the production of this result." He proceeds to point out that wherever a land surface was formed, vegetation quickly sprang up, and furnished the material for beds of coal. When these swampy flats were again submerged, fresh deposits of mud and sand covered the rich, carbonaceous soil, and entombed the trees and plants which grew in it.

Such, according to Professor Green, is a brief sketch of the submarine changes attendant upon the gradual deposition of the Carboniferous rocks of Yorkshire, and it is applicable to all other regions where a similar series of beds is found. As far as the earlier members of this series are concerned, there is nothing very remarkable in their mode of formation. They are simply masses of limestone, shale, and sandstone which can be paralleled by similar groups in other geological systems; but the upper members have been accumulated under conditions which have been much less frequently repeated during geological time—conditions, indeed, which have never prevailed again in the European area to the same extent as they did in the Carboniferous period. It will, therefore, be worth while to describe these conditions a little more fully, and to see what conclusions may be drawn from them as to the general state of physical geography towards the close of this long period.

We have seen that the best authorities are agreed that the coal-seams are land-growths, but that their materials were accumulated on swampy alluvial tracts which were never elevated much above the mean level of the sea. We have seen also what a wide extension the Coal-measures had over the British area, and that what are now separate basins or coalfields were originally connected and continuous areas. But this great development of Coal-measures is by no means peculiar to Britain; coalfields found in many parts of the Continent, notably in Fra Belgium, Germany, and Russia, everywhere presentin similar aspect and a similar succession of measures, mak

it certain that they belonged to one natural province or geographical area.

We must conclude, therefore, that over a large part of what is now Europe there existed vast tracts of alluvial land but little above the sea-level, the conterminous deltas, in fact, of the rivers which drained the surrounding land, just as Holland is the conterminous delta of the Rhine, Meuse, and other rivers. It is as if an area as large, or larger, than that covered by the Mediterranean Sea, were slowly silted up and converted into one enormous swamp. To bring about such a result there must have been many rivers of large size emptying themselves into this sea, rivers comparable to the Rhine, the Rhone, the Po, and the Vistula, and for the supply of such rivers the surrounding continents must have possessed mountain ranges comparable to those of Central Europe, and must have been watered by a copious rainfall.

Again, although the area of deposition was constantly widened by subsidence, yet the detritus brought down from the higher to the lower levels was always sufficient to counterbalance this depression. Further, it would appear that all this material must have been obtained from the surface of the land, and transported by fluviatile agencies, for there could have been very little coast-erosion round the borders of this land-locked sea.[1] Rain and frost must therefore have been constantly at work on the surface of these continents, disintegrating and dislodging the rocks of which they were composed, while the rivers would be chiefly employed in carrying off the detritus so prepared, for the continued depression would have diminished their erosive capacity in accordance with the principles enunciated in another place.[2]

The student will remember that deposition is a measure of detrition, and we may [illegible], therefore, in this enormous mass of [illegible]ments a measure of the detrition which took place, and [illegible] material removed from those portions [illegible] continents which drained into that [illegible] above.

[1] It is [illegible]n, the rise and fall [illegible]

[2] "Ph[illegible]87.

Now the time necessary for the progress and consummation of all these natural operations must have been enormous, and yet the changes in physical geography must have been so slight and so slow throughout this great length of time that they did not materially alter the relative positions of land and sea, or interrupt the process of swamp formation; this, then, is the peculiar and remarkable point in Carboniferous history which I desire to impress upon the reader's mind, that the latter half of it was a period of internal quiescence, a period in which terrestrial disturbances were at a minimum, and consequently when the surface agencies of change were able to continue their course of action to a greater extent than usual.

It was stated in Volume I. ("Physical Geology"), p. 134, that if these surface agencies were allowed full play, and were not checked or balanced by terrestrial movement, every continent would gradually be reduced in height, and worn down to a level but little above that of the sea, while the surrounding waters would be choked and shallowed by the materials poured into them from the wasting land. It would appear, therefore, that the Carboniferous was a period when this theoretical result was more nearly approached than it ever has been before or since; when the continents were gradually lowered by the combined action of detrition and depression, the area of high ground being continually diminished, but the area of low-lying, swampy ground at or about the sea-level being continually increased.

Such a condition of affairs will account for the remarkable uniformity of life which prevailed throughout the Carboniferous period, a fact to which attention was called on p. 168. The geographical changes being so slight, and during the earlier portion of the period consisting chiefly in an extension of the marine areas at the expense of the land, we may suppose that the seas retained their same relative positions and connections throughout an enormous lapse of time, and that the denizens of these seas spreading far and wide through the broadening water-spaces found everywhere a similarity of conditions that enabled them to flourish and survive without change or variation.

Later on, when the seas were shallowed by the continued

deposition of material derived from the continents, and when the higher land was everywhere encircled by a wide belt of low-lying jungle and swampy ground, intersected by sluggish water-ways and lagoons, the conditions would be exactly those where nature would present a monotonous and uniform aspect, and where the plants and animals which had established themselves would be likely to maintain their existence unchanged so long as the same conditions prevailed. In this way it seems possible to explain the remarkable persistence of life-forms in the Carboniferous rocks of Europe, and to account for the phenomena presented by one of the most remarkable periods of the world's history.

# CHAPTER VII.

## Dyas or Permian System.

### Classification and Subdivisions.

MUCH controversy has recently arisen with regard to the classification of the rock-groups which intervene between the Carboniferous and the Jurassic systems. Formerly, and up to 1841, the whole of them were grouped together under the name of New Red Sandstone, and classed as Mesozoic, but in that and subsequent years, Sir R. I. Murchison advocated their separation into two great divisions, and, relying solely on the Carboniferous affinities of the fossils in the lower division, he retained that in the Palæozoic series, and regarded the upper division as the base of the Mesozoic series. At the same time he named the lower rocks "*Permian*," from the ancient kingdom of Permia in Russia, while for the upper rocks the German name of *Trias* has been generally employed.

Although the name Permian has hitherto been accepted in England, it has not been adopted in Germany, for the very good reason that Murchison's grouping of the German rocks was in opposition to the views then held by German geologists, and has since been proved to be erroneous. Another name has been gradually coming into favour, that of *Dyas* (from δυας, duality), proposed by M. J. Marcou in 1859, and designed to convey the idea of the German series being everywhere divisible into *two* groups (upper and lower), just as the Trias is divisible into three such groups. This name is now generally used on the Continent, and though not altogether a good one, is certainly better than "Permian," which is connected with too many errors for general adoption.

The question as to whether Murchison was justified in

separating the two series so widely as to refer one to Palæozoic, and the other to Mesozoic time, is one upon which much difference of opinion exists, and about which it is perhaps unnecessary to decide. Although there can be no question about the Palæozoic affinities of the fossils found in the Dyassic rocks, yet, on the other hand, there is ample proof that the physical break between the Carboniferous and the Dyas was considerable, and that great changes in the physical geography of the world took place in the interval. I have, therefore, preferred to regard the Dyassic rocks as formed during a period of transition from the one order of things to the other, and therefore as belonging to neither.

If I were compelled to draw a hard and fast line between the Palæozoic and Mesozoic divisions of time, and to be guided entirely by palæontological considerations, I should doubtless follow Murchison in retaining the Dyas in the Palæozoic, and in commencing the Mesozoic with the Trias. But although inclined to give full weight to the evidence derived from fossils, I cannot but acknowledge the influence which must have been exercised by the peculiar geographical conditions which prevailed in the North-European area at this period (see p. 251). The Carboniferous sea was broken up, and large portions of it were rapidly isolated in a manner which prevented the gradual introduction of a new fauna. Could we really expect the fauna of the Northern Dyas to be any other than it is—a dwindled and modified remnant of Carboniferous life; and this assemblage would naturally remain in possession until submergence allowed another to take its place. No such depression, however, occurred till the middle of what we call Triassic time; but it is probable that in more southern seas the differentiation of life-forms was rapidly progressing through all Dyassic time, and that the changes were in the direction of the marine Muschelkalk fauna.

I would admit, therefore, that there may be exceptions to the principle of classifying by palæontological evidence, and that we must in each case have regard to the special conditions which may have affected the fauna of the province under examination.

Again, while the importance of the stratigraphical break between the Carboniferous and Dyas is not to be minimized, yet I cannot range myself at present with those who advocate the union of the Dyas and Trias into one system, because it is equally impossible to ignore two prominent facts—(1) the extreme difference in the marine faunas (however caused), (2) the existence of a well-marked unconformity between the two formations, both in England and Germany.

The real fact is, that the Dyassic system of these two countries is marked off by decided unconformities, both from the rocks below and from those above, the greater break being at its base. Under these circumstances, and while admitting that good reason may be found in the future for uniting the Dyas and Trias into one system[1] (under some such name as *Mercian*), I content myself with stating the facts and keeping them separate for the present.

The Dyassic rocks vary so greatly in different districts, both in Germany and Britain, and there is still so much doubt with respect to the inclusion or exclusion of certain beds both at the base and the summit of the system, that it is impossible at present to establish any classification that is generally applicable.

In Germany, however, where the rocks are typically developed, they fall naturally into two groups, as below:

2. Magnesian Limestones (Zechstein),
1. Red Sandstones (Rothe-liegende),

and the same Dyassic arrangement is found in some parts of Britain, though in other parts the system is represented either wholly by magnesian limestone with a base of marly shale, or entirely by red sandstones and calcareous breccias. There is, however, no proof that the red rocks are as a whole older than the limestones, and the notion of their being so is a mere assumption founded on their lithological

[1] "The further investigation of both the Alpine and Russian series seems thus far to indicate that in these regions we may find the transition series which we know (on *à priori* grounds) must exist, or have existed, somewhere."—A. Irving in "Geol. Mag.," Dec. 2, vol. ix. p. 498.

similarity to the German Rothe-liegende. This question will be referred to again hereafter.

## Life of the Period.

The fauna of the Dyas is a survival of the Carboniferous, the majority of the fossils belonging to Carboniferous genera, though mixed with these are a few which may be considered the precursors of Mesozoic types; these latter are all Lamellibranchs, which are proportionally more numerous than in earlier periods, this also foreshadowing the numerical importance which they attain in Mesozoic times. Gasteropods are limited to a few genera, and the individuals are rare and small, as if dwarfed by the conditions under which they lived. Cephalopods have almost disappeared, a few *Nautilus* and *Orthoceras* only surviving. No Crustacea of any kind have yet been discovered, and of the ancient order of Trilobites there is no representative. Of Corals and Echinoderms there are very few, but Polyzoa are not uncommon.

Brachiopods belonging to the genera *Camarophoria*, *Productus*, *Spirifera*, and *Strophalosia* are abundant.

Fish are well represented, the principal genera being *Acrolepis*, *Palæoniscus*, *Platysomus*, *Amblypterus*, and *Pygopterus*.

Amphibia seem also to have flourished, Labyrinthodont footprints being not uncommon, and bones are occasionally met with, referred to *Lepidotosaurus* and *Zygosaurus*.

The Marl Slate and Kupferschiefer yield remains of the earliest Lacertian Reptile (*Proterosaurus*) which has yet been found in Europe.

The fossils are chiefly found in the Zechstein and Marl Slate, and the following are some of the most characteristic fossils of the English and German Dyas.

*Plants.*—Neuropteris Huttoniana, Odontopteris obtusiloba, Callipteris conferta, Calamites gigas, Walchia piniformis, W. hypnoides.

*Polyzoa.*—Fenestella plebeia, Synocladia virgulacea.

*Brachiopoda.*—Camarophoria crumena (Schlotheimi), Strophalosia lamellosa, Producta horrida.

*Lamellibranchs.*—Avicula (Monotis) speluncaria, Pleurophorus costatus, Bakevellia antiqua, Axinus (Schizodus) truncatus, A. Schlotheimi.

*Gasteropoda.*—Loxonema fasciatum, Macrocheilus symmetricus, Pleurotomaria antrina, Turbo mancuniensis.

*Cephalopoda.*—Nautilus Frieslebeni.

*Fish.*—Platysomus striatus, Palæoniscus comptus, P. macropomus, Pygopterus mandibularis, Acrolepis Sedgwickii, Amblypterus macropterus.

*Amphibia.*—Lepidotosaurus Duffii, Dacyceps Bucklandi.

*Reptilia.*—Proterosaurus Speneri.

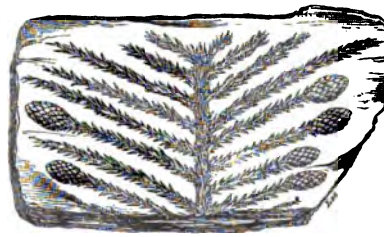


Fig. 46. Walchia hypnoides, Marl Slate, Germany.

## Range and Relation to Rocks below.

Except in the north-east of England the Dyassic rocks occur only in fragmentary strips and patches along the borders of the Coal-measure basins. This disconnected mode of occurrence is partly due to the overstepping of the Trias, under which many areas of Dyas are buried and concealed, and partly of course to the removal of large portions by erosion. Their limitation, however, to certain districts and their entire absence in the south of England are facts due to the conditions under which they were originally deposited; these conditions will be described on a future page.

The most southerly point to which they have been traced is at the northern end of the Malvern Hills. They border parts of the Worcester, Shropshire, Staffordshire and Den-

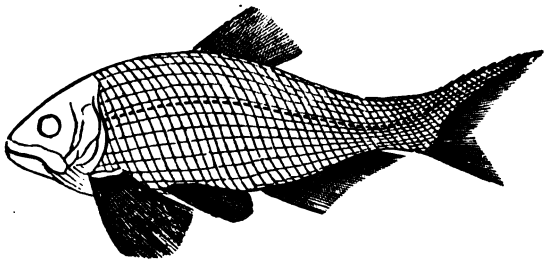


Fig. 47. Restoration of Amblypterus.

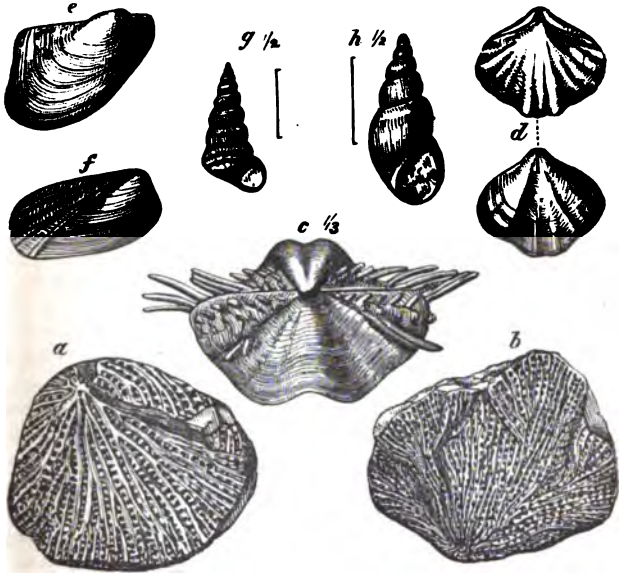



Fig. 48. Dyassic Fossils.

*a*. Synocladia virgulacea.
*b*. Fenestella retiformis.
*c*. Producta horrida.
*d*. Camarophoria Schlotheimi.
*e*. Bakevellia antiqua.
*f*. Pleurophorus costatus.
*g*. Loxonema fasciatum.
*h*. Macrocheilus symmetricus.

bighshire coalfields, and isolated patches are found at intervals through Lancashire and Westmoreland, in the valley of the Eden and in the south-west of Scotland. Throughout this range they are generally unconformable to the Carboniferous rocks, the amount of material removed before their deposition being least in Denbigh and greatest in Cumberland, where they overstep the edges of the Coal-measures and Millstone Grit so as to rest upon the Carboniferous Limestone.

In the east of England the Dyas forms a continuous strip bordering the Carboniferous tract from Sunderland southward to Nottingham; along this line it everywhere rests on the upturned edges of the underlying rocks, and the unconformity is plainly visible on any geological map which shows the Coal-measure basins. Its eastward subterranean extension is very interesting, several borings recently made far to the east of its outcrop showing that it maintains its thickness in that direction, while southward it thins out against a shore-line of Palæozoic rocks, and is consequently absent in the boring at Owthorpe (south-east of Nottingham), where Trias rests on Carboniferous.

An outlying tract of rocks supposed to be of Dyassic age occurs in connection with the Warwickshire coalfield, but here the discordance is very slight, and it is by no means certain that the beds are rightly referred to the Dyas and are not rather part of the Upper Coal-measures, in which series slight discordances and surfaces of erosion are known to exist elsewhere.

In Scotland Dyassic rocks are only found in the extreme south-west, and in Ireland they are confined to the extreme north-east; the waters in which they were formed never having extended far over either of these countries.

As the most complete sequence is to be found in the north-east of England, it will be convenient to describe this first as a typical area, with which the others may be more or less fully compared.

## Stratigraphy.

### 1. *North-Eastern Counties.*

Dyassic rocks occupy the coast-line of Northumberland and Durham from Tynemouth to Hartlepool, and their base can be followed inland from South Shields to Auckland and the valley of the Tees. Where the beds are fully exposed, the succession is as follows:—

| | | Feet. |
|---|---|---|
| Magnesian Limestone. | Yellow concretionary limestone . . | 200 |
| | Brecciated limestone, with fossils . . | 150 |
| | Compact limestone . . . . | 200 |
| | Brown calcareous shale ("Marl Slate") | 3 |
| | Friable yellow sand from . . . | 0 to 96 |
| | | 649 |

The red and yellow sandstones with plants, formerly considered as the base of the Dyas, are now known to belong to the Carboniferous system.

Although their strike is at first nearly in accordance with that of the underlying Coal-measures, yet they do not participate in the anticlinal flexures which give an east and west strike to these measures in South Durham. Near the valley of the Tees the Dyas oversteps the Coal-measures, and rests on the Millstone Grit; at the same time the greater part of it is overlapped by the Triassic sandstone, the width of the tract occupied by the Magnesian Limestone being gradually diminished, till between the valleys of the Tees and the Ouse only a narrow strip of it remains between the Trias and the Carboniferous rocks, and this is hidden by superficial deposits.

Near Bedale in Yorkshire the overlap lessens again, and the Dyas extends southward in a broader strip between the Carboniferous and the Trias as far as Nottingham, for a distance of nearly ninety miles. In Yorkshire, near Pontefract and elsewhere, the Upper Limestone becomes thinner, but the marl slates are thicker than in Durham, and sometimes rest on white and yellow sands, which in

turn rest on an eroded surface of red marls and sandstones belonging to the Upper Coal-measures (see p. 196). In South Yorkshire the succession may be summarized as follows:[1]—

| | Feet. |
|---|---|
| Upper red marls | 50 |
| Upper (Brotherton) limestone | 60 |
| Middle red marls | 30 |
| Middle limestone, thick-bedded | 150 |
| Lower limestone | 120 |
| Blue limestones and shales | 15 |
| Quicksands and breccia | 10 |
| | 435 |

Traced southward into Nottinghamshire, the Upper Limestone thins southward and is at the same time overlapped by the Trias, so that the thickness of the Dyas at its outcrop is very much diminished, being as follows:—

| | Feet. |
|---|---|
| Middle marls and sandstones | 20 to 30 |
| Magnesian limestone (Lower) | 60 to 70 |
| Marl slates | 30 to 50 |

Eastward below the Trias the limestone maintains its thickness, and the marl slates thicken to 100 and 200 feet, but southward near Kimberley the limestone passes into a yellow calcareous sandstone about thirty feet thick, resting on fifteen to twenty feet of shaly marl, with a few feet of coarse breccia at the base.[2] This diminution in thickness is evidently an indication that we are in this direction approaching the southern shore of the Dyassic sea. The breccia contains angular fragments of sandstone and shale derived from the Coal-measures on which it rests, together with pebbles of slate, quartz, and quartzite, and it is not unlikely that these were derived from a northerly prolongation of the Charnwood Forest rocks.

North of Nottingham the Triassic sandstones sweep

[1] See E. Wilson on "Permian Formation, Midland Nat.," vol. iv.

[2] For details consult the "Geology of the Country round Nottingham, Geol. Survey Memoir," by W. T. Aveline, p. 12.

southward across the Dyas, and westward up the valley of the Trent, concealing all the underlying rocks.

We may here notice several borings made in recent years, which give us some information regarding the character of the formation in its eastward subterranean extension.

Near Middlesbrough, in Yorkshire, two borings were made, in 1862 and 1874 respectively, through the Trias, and into the uppermost Dyassic beds, consisting of magnesian limestone with *Axinus*, underlain by a remarkable series of beds which are not found anywhere along the outcrop. The following is an abstract of the borings:—

| | I. | II. |
|---|---|---|
| Surface and glacial deposits | 43 | 77 |
| Triassic marls and sandstones | 1,163 | 1,050 |
| Rock salt (and gypsum in II.) | 100 | 134 |
| Magnesian limestone | 7 | 52 |
| Grey limestone | | 15 |
| Gypsum, rock salt, and marl | | 27 |
| | 1,313 | 1,355 |

Another more complete and interesting section of the Dyas is furnished by the boring at South Scarle, near Newark. In the following account I follow Mr. E. Wilson, who carefully examined the cores, and has supplied the most accurate description of the beds.

| | | Ft. | In. |
|---|---|---|---|
| Surface gravel and drift | | 21 | 0 |
| Lower Lias clay and limestone | | 34 | 0 |
| Rhætic shales | | 45 | 0 |
| Trias. | Keuper marls and sandstones | 866 | 0 |
| | Bunter sandstones | 564 | 0 |
| Dyas. | Upper marls | 88 | 6 |
| | Upper limestone | 40 | 6 |
| | Middle marls | 141 | 0 |
| | Lower limestone | 26 | 0 |
| | Marl slates (shales and dolomites) | 193 | 0 |
| Carboniferous red marls | | 10 | 0 |
| | | 2,029 | 0 |

### 2. *Midland Counties.*

A few small patches of red marl, with beds of breccia, occur at several places round the Leicestershire coalfield, but their thickness is always small, and it is not at all certain that they belong to the Dyassic series. When the Dyas decidedly sets in again to the south of the Warwickshire coalfield, it exhibits a very different facies from that of the north-eastern counties. It consists here of red, brown, and purple sandstones, with red marls, and occasional beds of calcareous breccia or conglomerate, the whole reaching a thickness of nearly 2,000 feet. These beds occupy a considerable area to the north and south of Coventry, and generally conform to the strike of the Upper Coal-measures, but slightly overlap the Spirorbis limestone in one or two places. The only fossils yet found are plants of Carboniferous genera, an obscure shell like *Strophalosia* and bones of *Lepidotosaurus*. In the breccia at Exhall fragments of Silurian sandstone (? Llandovery) and of Carboniferous limestone were found.

Dyassic rocks flank the South Staffordshire coalfield on the east and west, and extend southward to form the hilly tract of ground known as the Clent and Lickey Hills. The highest part of these hills consists of coarse breccia, which includes large angular boulders of various older rocks—Silurian sandstone, limestone, slates, and many fragments of felstone, greenstone, and felspathic ash. This breccia is about 400 feet thick, and rests upon beds of red and purple sandstone, with bands of concretionary limestone, undistinguishable from the cornstones of the Old Red Sandstone. This lower group is from 600 to 700[1] feet thick, and conforms to the dip of the Upper Coal-measures (see section, fig. 55, p. 274). The breccia is overlapped northwards by the Trias, but strips of the sandstones varying in breadth are faulted against the Coal-measures on either side of the coalfield extending to Great Barr on the east and to Essington Wood on the west.

[1] It was formerly supposed to be 1,500 feet thick, but the lower parts are certainly Upper Coal-measures, and the true base of the Dyas has not been fixed.

In North Staffordshire a series of red and purple sandstones, marls, and cornstones, similar to those above described, forms a long tract along the southern margin of the coalfield from Audley on the north-west by Madeley Keel and Newcastle to Barlaston, near Stone. They rest with a slight discordance upon the Upper Coal-measures, and are covered unconformably by the Bunter conglomerates. Their total thickness appears to be from 600 to 700 feet; they evidently represent only the lower group of the South Staffordshire series, and may properly belong to the Coal-measures.

Dipping westward from the South Staffordshire coalfield beneath the Trias, the Dyassic Beds emerge again on the eastern side of the Shropshire coalfield, where the best and most complete sections of the Midland series are to be found. Fig. 49, p. 242, represents the section at Enville, near Bridgnorth, where Professor Hull describes the following succession:—

| | | Feet. |
|---|---|---|
| Upper. | Brown and purple sandstones and red marls | 400 |
| Middle. | Breccia of felspathic trap, syenite, &c. | 60 to 120 |
| | Sandstone and marl, with beds of calcareous conglomerate | 80 to 120 |
| Lower. | Brown and purple sandstones and red marls | 800 |

These beds form a strip some ten miles in length along the eastern side of the coalfield, and rest with a slight overlap upon the Upper Coal-measures. Their former extension to the west and south is attested by a series of small outliers. At Wars Hill, near Kidderminster, a patch of breccia, underlain by brown sandstone and marl, with a bed of calcareous conglomerate, rests on the upturned Lower Coal-measures, close to their junction with the Old Red Sandstone. At Church Hill, in Worcestershire, a patch of similar breccia rests directly on the same measures; the fragments composing this breccia are very large and angular, and can be identified with rocks of Cambrian and Silurian age lying to the north-west. Small

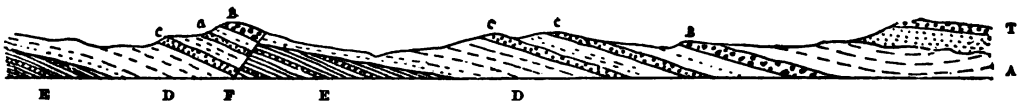



Fig. 49. Section across the Dyassic Beds near Enville (after Professor Hull).
Distance about 5 miles.

T. Trias (base of).
A. Upper Sandstones.
B. Felspathic Breccia.
C. Calcareous Conglomerates.
D. Lower Sandstones.
E. Carboniferous Rocks.
F. Fault.

outliers of the breccia occur on Woodbury and Abberley Hills, where they rest on the truncated edges of Silurian rocks, and the most southerly patch is that on Berrow Hill, at the southern end of the Malvern range, and resting on Silurian rocks.

A strip of Dyas runs along the northern side of the Shrewsbury coalfield, the series resembling that of the Bridgnorth area, and being about 1,000 feet thick. At Alberbury and Cardeston there are thick beds of calcareous breccia and conglomerate, in part dolomitic, and nearly 400 feet in thickness. This breccia consists principally of fragments of limestone embedded in a reddish sandy calcareous matrix; some of them are apparently derived from the Carboniferous Limestone, and some from the Spirorbis Limestone of the Upper Coal-measures; pebbles of white quartz, slate, and chert also occur. The underlying beds, consisting of red marls and brown calcareous sandstones, attain a thickness of about 750 feet.

Passing to North Wales, we find the Dyas overlapped by the Trias in the Severn valley, east of the Breidden Hills, but it sets in again along the eastern margin of the Denbighshire coalfield, and extends from near Oswestry to Gresford, where it is once more overlapped and concealed by the Trias. Good sections are found in the banks of the Dee, which crosses the middle of the tract; here it succeeds the red and green series of the Upper Coal-measures without any apparent unconformity, and consists of red and purple sandstones, interstratified with thick beds of red marl; a few bands of cornstone or earthy limestone also occur, but there is a complete absence of conglomerates and breccias, although the total thickness seen is about 1,500 feet.

It is interesting to find a narrow strip of Dyassic beds accompanying the Coal-measures in Anglesea; they consist of red marls, sandstones, and conglomerates, and are about 400 feet in thickness.

### 3. *North-Western Counties.*

**Lancashire.**—Crossing the Cheshire plains to the neighbourhood of Stockport and Manchester, we find Dyassic rocks again setting in along the margin of the Lancashire coalfield. The sedimentary type is here different from both of those already examined, and is to some extent of an intermediate character between the limestone type of the North-east and the arenaceous facies of the Midlands. Moreover, near Rushton Spencer, about halfway between Audley and Stockport, there is an interesting little outlier, consisting of red and mottled sandstones, with partings of red sandy marl, overlain by red and white marls, which are succeeded by the Triassic pebble beds; the whole lying in a synclinal trough in the valley of the Dane. In mineral character these beds resemble the Lancashire type more than that of North Staffordshire; their thickness is about 80 feet.

The Lancashire beds commence near the village of Poynton, south of Stockport, and extend northward between Ashton and Manchester, curving round westward with the trend of the coalfield, and though broken by faults they are traceable as far as Leigh and Wigan.

Near Stockport they are separable into two groups—(1) a lower, consisting of soft bright red and variegated sandstones, estimated at some 1,500 feet in thickness; (2) an upper, composed of red marls, with some beds of hard stone, 130 feet. The latter are only seen in faulted strips to the west of Stockport, being overlapped eastward by the Trias. The same series is found near Manchester, where the lower beds are sometimes called the Collyhurst sandstone; their thickness, however, is much less, varying from 375 feet on the east to only 20 and 12 on the west of Salford. The upper group consists of marls and limestones, with a maximum thickness of 250 feet, and these beds have yielded fossils of Magnesian Limestone types.

Near Wigan an interesting section is exposed in the sides of a dell called Skillaw Clough; this has a still greater resemblance to the North-eastern type, and is as follows:—

| | Feet. |
|---|---|
| Yellow magnesian limestone . . . | 6 |
| Red and purple shales . . . . | 30 |
| Soft red and brown sandstones . . . | 60 |

Small outlying patches of Dyas have been found in several parts of North Lancashire, serving to show that they had originally a continuous extension over the county; larger tracts occur near Lindale, on the northern shore of Morecambe Bay, and again from Ulverston to Rampside in the Furness promontory.

**Cumberland.**—The tracts last-mentioned lead on to the strip of Permian which borders the Cumberland coast from the estuary of the Duddon to St. Bees' Head. The beds forming this tract are described as follows:—

| | Feet. |
|---|---|
| Red sandstones of St. Bees . . . | 600 |
| Red and green marls, with gypsum . . | 30 |
| Magnesian limestone, with fossils . . | 11 |
| Breccia of limestone fragments . . . | 3 |
| | 644 |

The breccia rests on an eroded surface of the purple Whitehaven sandstone, which was formerly regarded as a member of the Dyassic system, but is now referred to the Carboniferous.

A still larger area of Dyassic deposits is preserved in the broad valley of the Eden, extending from Kirby Stephen, in Westmoreland, by Appleby and Penrith, to Longtown, north of Carlisle, and westwards to the sea at Allonby. On the east it is bounded by the great Pennine fault, and on the west also it is faulted for some distance against the Carboniferous Limestone. Everywhere the Dyas rests unconformably on the Carboniferous, and it attains a much greater thickness than in any other district; red sandstones and breccia, consisting of limestone pebbles embedded in a sandy matrix (locally called *brockrams*), are the most prominent members of the series.

At Hilton Beck, near Appleby, the following section was measured by Mr. Goodchild:—

| | Feet. |
|---|---|
| St. Bees sandstone[1] | 500 |
| Red shales | 250 |
| Magnesian limestone, with shales and impure coal | 55 |
| Lenticular breccias, with red sandstone | 150 |
| False-bedded red sandstone | 300 |
| Lower breccias (brockrams) | 100 |
| | 1,355 |

All these beds thicken considerably towards the north, and resolve themselves into two massive sandstone formations, separated by a zone of red shales; thus between Southwaite and Newbiggin (seven miles south of Carlisle) we have the following series, according to Mr. Goodchild :—

| | Feet. |
|---|---|
| St. Bees sandstone | 1,500 to 2,000 |
| Red shales | 400 to 500 |
| Penrith sandstone | 1,000 |
| | 2,900 to 3,500 |

These Dyassic sandstones have a bright brick-red tint, the Penrith being rather lighter and brighter than the St. Bees rock. Both are therefore easily distinguishable from the purple-grey sandstones of the Upper Coal-measures, which were included with the Penrith sandstones before the country was mapped by the officers of the Geological Survey.[2] In the north of the county the St. Bees sandstone, with a brecciated base, rests directly on these purple Carboniferous sandstones.

### 4. *Scotland.*

Deposits of Dyassic age only occur in the south-west of Scotland, and here the sedimentary type is again entirely

[1] It has recently been suggested that the St. Bees sandstone is really of Triassic age, and that the Dyassic series terminates with the red shales.

[2] See a paper by T. V. Holmes, "Proc. Geol. Assoc.," vol. vii. No. 7.

arenaceous, without any intercalation of magnesian limestone.

Sandstones and breccias, similar to those of Cumberland, occur in the south of Dumfriesshire, occupying several separate basins, one extending from the mouth of the Nith, by Dumfries to Friar's Carse, the Dyas here overlapping the Carboniferous, and resting upon Lower Silurian rocks, from which their materials have been chiefly derived. Near Dumfries are some beds of coarse sandy breccia, the fragments being chiefly greywacke, felstone, and grey shale; but the mass of the formation consists of bright red sandstones such as those of Corncockle Muir, which are celebrated for containing the foot-prints of large Saurians and other reptiles.

Near Thornhill, in Nithsdale, there is another basin, resting partly on Silurian and partly on Carboniferous rocks. The southern and central portions of this area consist entirely of brick-red sandstones, but in the northern part lava-flows and volcanic detritus are interstratified with the lowermost sandstones, the series being divisible thus:—

3. Brick-red sandstones, with some shales and clays.
2. Brick-red sandstones, with bands of volcanic tuff.
1. Sheets of porphyrite, with tuff and sandstone.

A small tract of red breccia borders the east side of Loch Ryan in Wigtownshire.

Two other basin-like areas of similar strata occur in Annandale, one round Lochmaben and Johnstone, and the other round Moffat.

In the centre of the Ayrshire coal-basin lies a pear-shaped area, occupied by rocks of a type similar to those of Thornhill. At the bottom are a series of porphyrite lavas and tuffs, which form a continuous band or rim round the little basin. Inside this rim, and above the volcanic group, are brick-red sandstones like those of Thornhill and Dumfries (see fig. 50, p. 249).

### 5. *Ireland.*

Dyassic rocks are only found at two or three localities in the north-east of Ireland, but, singularly enough, they

include representatives of both the arenaceous and magnesian limestone types.

Magnesian limestone has been found at two localities: one at Tullyconnell, near Ardtrea, county Tyrone; the other at Cultra, on the southern shore of Belfast Lough, where they rest on red marls, and are faulted against Carboniferous rocks. Shells of *Schizodus*, *Bakewellia*, &c., have been found in them, proving their identity with the Durham limestones.

Shore-beds of Dyassic age have been identified by Professor Hull as occurring beneath the city of Armagh, the exposure at the Armagh marble quarries being as follows:—

| | |
|---|---|
| 3. Boulder beds, resting on conglomerate.<br>2. Limestone breccia.<br>1. Carboniferous limestone. | 20 feet. |

The rocks here are of a deep red colour, rudely stratified, and the breccia at the base consists of limestone fragments in a matrix of compacted sand, like the Brockram of Cumberland. The blocks in the overlying boulder bed are of all sizes up to two feet in diameter, and consist of purple grits and felspathic sandstones derived from the Silurian and Old Red Sandstone districts to the north or west.

## Volcanic Rocks.

No actual lavas or tuffs of Dyassic age have yet been found in England, the felstone blocks of the trappean breccia of Staffordshire being derived from some older formation.

In Scotland, however, volcanic action was rife, the greater part of that country being probably a land surface in Dyassic times. Many of the volcanoes were doubtless on this land, and of these there are no traces remaining, except the pipes or necks through which the lava rose. In the Ayrshire and Thornhill basins, however, some of the contemporaneous lava-flows are preserved beneath the sedimentary rocks; these have already been mentioned (p. 247),

and the following is a fuller account taken from the "Geological Survey Memoirs."[1]

The lower or igneous zone consists of a succession of beds (or sheets) of porphyrite and melaphyre, marking different eruptions of volcanic material. The prevailing kind of rock is a dull reddish brown, amygdaloidal, porphyrite consisting essentially of a crystalline basis of plagioclase felspar, through which much hæmatite is diffused. Augite appears in some specimens, and the amygdaloidal kernels are usually steatite.

Over these sheets of porphyrite comes a group of stratified rocks, consisting essentially of the ordinary Permian (*i.e.* Dyassic) brick-red sandstone, but containing an abundant intermixture of tuff and porphyrite fragments, either aggregated into lenticular seams, or scattered more or less abundantly through the body of the sandstone.

Fig. 50. Section across the Dyassic basin of Ayrshire.

| | |
|---|---|
| *f.* Basalt dyke. | *c.* Beds of tuff. |
| *e.* Volcanic necks. | *b.* Porphyrite sheets. |
| *d.* Red sandstones. | *a.* Palæozoic rocks. |

Besides these interbedded volcanic masses, these areas furnish other evidence of the number and activity of the Permian volcanoes. Outside the Permian basin, the Coal-measures are pierced by numerous large pipes filled with a coarse unstratified agglomerate, and usually appearing at the surface as small rounded hills or hillocks. Sometimes the agglomerate includes a core or column of porphyrite, and the coal-seams in their neighbourhood are often charred or altered into columnar coke. "There can be little doubt that in these columns or necks we see part of the vents through which volcanic material was ejected in Permian times." The necks are especially numerous in the Dalmellington coalfield, but they occur also in Renfrewshire and Lanarkshire, piercing the highest Coal-measures in those counties.

[1] Explanations of Sheets 9, 14, and 22, Scotland.

### Continental Distribution.

Transitional beds between the Carboniferous and the Trias, *i.e.*, between the Palæozoic and Mesozoic divisions of palæontological time, are found in most countries where Carboniferous rocks occur. They are known in France, Germany, Bohemia, Poland, and Russia. Here, however, it will suffice to describe the German and Russian series.

**Germany.**—The typical Dyassic series of Germany is found in the Thuringerwald, and on the flanks of the Hartz Mountains. Here it consists of two principal members: (1) the *Rothe-liegende*, a group of red sandstones and conglomerates resting unconformably on the Coal-measures, and varying greatly in thickness; (2) the *Zechstein*, a magnesian limestone with a thin band of black shale at the base, called *Kupfer-schiefer*, and which is the exact analogue of our marl slate. The lower part of the Zechstein is a massive thick-bedded limestone, the upper part is thin-bedded (Platten-dolomit), and sometimes contains beds of gypsum. Its upper surface is eroded and covered by soft shady sandstones locally termed the Bunter-schiefer.

It is on account of the persistent development of these two groups in northern and central Germany that the system has been termed the Dyas. But when this Dyas is traced southward into Bavaria and Bohemia, the calcareous members die out, while the arenaceous members increase in thickness, till the whole series consists of sandstone and conglomerate with only thin local beds of limestone or calcareous breccia. This lateral change of sedimentary type is analogous to that which takes place in England, and in both countries the upper part of the arenaceous group may be correlative with the upper part of the calcareous group.

**Russia.**—The Dyassic rocks seem to have extended continuously eastward from Germany through Russia to the Ural Mountains, on the flanks of which they are largely developed, and it was from the ancient kingdom of Permia, which included the modern provinces of Perm, Kasan, Orenburg, &c., that Sir R. I. Murchison gave these rocks the name of Permian. Here they cease to be a "Dyas,"

and consist of a variable succession of sandstones, marls, limestones, and gypsum beds; they are overlain by red sandstones and conglomerates, which Murchison considered to be of Permian age, but which may prove to be Triassic.

It has been found, indeed, that both in Russia and Germany Murchison included too much in his Permian system; in Russia he made a threefold division of the series into (1) Lower Sandstone, (2) Limestones and Marls, (3) Upper Sandstones, and thinking he found a parallel series in Germany, he correlated the Russian Upper Sandstone with the Bunter-schiefer which overlie the Zechstein in Germany.[1] These Bunter-schiefer have consequently been for a long time included in the Permian series, but the best authorities are now of opinion that they belong to the Trias.

## Physical Geography.

In Chapter VI. the Carboniferous period was described as one of quiescence, during which the forces of terrestrial disturbance were in abeyance; but as periods of calm and storm ever alternate in the atmosphere outside our earth, so also do periods of quiescence and disturbance seem to have succeeded one another within the earth itself. Certain it is that the calm of Carboniferous times was followed by an epoch of great disturbance in the European and Atlantic areas, which ended in the establishment of an entirely new order of things.

The general appearance of terrestrial surfaces during the formation of the Coal-measures was described in the last chapter; the conglomerates and sandstones of the Upper Coal-measures give evidence that geographical changes were setting in, but subsequently more forcible movements took place, and the Dyassic period was ushered in by great upheavals and subsidences involving very

[1] Until it has been ascertained how much of the Russian group is really homotaxial with the German Dyas, the term *Permian* may be conveniently retained as a name for the Russian series, which is so different from that of Germany and England.

extensive changes in the physical geography of the northern hemisphere.

"During the Upper Carboniferous epoch," says Professor Hull,[1] "there seems to have existed a vast continental area stretching southwards from the Arctic regions, embracing Greenland or its representative, and occupying the North Atlantic of the present day (see frontispiece). The boundaries of this continent, east and west, approached the shores of the British Isles and of Western Europe on the one side, and of the North American continent on the other." At the close of the Carboniferous period there appear to have been important upheavals of land on either side of this continent, resulting in the formation of certain mountain ranges: the Alleghanies in America date from this epoch, as do also the Pennines in Britain, and certain east and west ridges which are now partially concealed by newer rocks, one of these being the subterranean ridge which strikes through the south of Ireland and England into Belgium. Simultaneously with these upheavals it is very probable that the ancient Atlantic continent was broken up, submerged, and converted into an open ocean; the depression of this Atlantic area being in fact the proximate cause of the upheavals on either side. Such, according to Professor Hull, was the genesis of the North Atlantic Ocean, and, apparently, it has never ceased to be an ocean from that time to the present day, though throughout the Mesozoic periods there was a large continuous tract of land to the west of England, of which Ireland is now the sole remnant.

The open Mediterranean sea of the Carboniferous period in Europe was converted into a large inland sea, like the Caspian of the present day, surrounded by a rocky and hilly continent, on which grew trees and plants of various kinds. Many of these plants are closely allied to those of the Carboniferous, but species belonging to the Yew and Fir tribes, which flourish on dry ground, preponderate over the reeds, ferns, and gigantic lycopodia which flourished in the Coal-measure swamps; while Sigillariæ are not found at all.

[1] "Contributions to the Physical History of the British Islands," 1882, p. 51.

Now for the first time do we find anything like a mass of land extending continuously through the continent of Europe, and stretching through France into the British Islands. All the south of England and Wales, the greater part of North England and Scotland, and nearly the whole of Ireland, formed a compact and united region of land, our islands being not then separated from one another by St. George's Channel.

It appears certain that the principal earth-throes, those which produced the more important disturbances of the Carboniferous rocks in Britain, occurred during the unrepresented period of time which intervened between the Coal-measures and the Dyas. The stratigraphical relations of the latter to the former make it clear that the disturbances, which bent the Coal-measures into the basin-shaped forms they now present, took place before any Dyassic strata were deposited. These movements resulted in the development of a double system of anticlinal and synclinal axes, one set running north and south, the other nearly east and west. It is impossible to say whether this double system of axes was formed simultaneously, or whether one set was formed first and the second set by a separate and subsequent movement, but it is certain that the interference or combination of these axes has produced the broad basins in which the Coal-measures are now found.

It is also certain that the Pennine chain (often called the backbone of England) began to be formed at this time; though there is some doubt whether it constituted a complete barrier, shutting off the western Dyassic area (Lancashire, Cumberland, &c.) from the main sea on the east, or whether there was communication between the two areas of deposition through a narrow strait across the centre of Yorkshire. There is certainly no positive evidence in favour of such a strait, and, on the whole, perhaps, the balance of evidence is against its existence. In that case there must have been complete land connection from Derbyshire to Scotland, and probably from Scotland to the north of Ireland, enclosing a second inland lake of much smaller dimensions, but still of respectable size, and rather larger than the modern Lake Huron.

Part of the site of this lake is now occupied by the Irish

Sea, and the deposits described in North-west England, in Scotland, and Ireland, were chiefly formed near its borders. It appears to have extended from Warwickshire and Worcestershire, on the south, to the Firth of Clyde, a distance of 280 miles, with an extreme width of about 160 miles. Arms of it ran up the Solway Firth and the valleys of the Eden, Nith, and Annan; and probably up to the Firth of Clyde; westward, a gulf extended into Ireland as far as Dungannon in Tyrone, and there may have been a bay stretching southward into St. George's Channel.

I am aware that my view of the geography of this period is very different from that published by Professor Hull,[1] who maintains the post-Dyassic and the pre-Triassic origin of the Pennine chain, but strong arguments against this view have been urged by Messrs. E. Wilson and J. J. H. Teall.[2] Again, the hypothetical ridge beneath Cheshire, for which Professor Hull contends, appears to me to rest on equally doubtful grounds. There is certainly very little similarity between the rocks of the eastern and western types, nor are the differences between those of Salop and Lancashire incompatible with their having been deposited in different parts of the same lake basin. As the lake was originally an uplifted area of the great Carboniferous sea, and its waters were probably saline, it is not surprising that a few marine shells should have lingered in its more central parts.

The slopes surrounding this lake seem in most places to have been steep, and the rivers running into it were consequently rapid, carrying down quantities of sand, and in some regions large stones and boulders, as in the breccias of the Midland counties. The size of the transported boulders in these breccias, their angularity, and the occasional striation of their surfaces, suggested to Professor Ramsay that they had been carried by floating ice. Many of the fragments can be identified with Welsh rocks, and it is highly probable that the Welsh mountains were then much more lofty than at present, and that snow may have accumulated on them in sufficient quantity to form glaciers.

[1] "Quart. Journ. Geol. Soc.," vol. xxv. p. 171, and "Physical History of the Brit. Isles," 1882, p. 90, and plate viii.

[2] "Geol. Mag.," Dec. 2, vol. vi., p. 500, and vol. vii. p. 349.

Some of these may have reached the level of the lake, and torrential streams bursting from others may have been equally active in carrying down the rock-fragments quarried from the frosty regions above.

On the northern borders of the lake volcanic forces came into play, and lava-flows with beds of volcanic ash were interbedded with the lacustrine sandstones (see p. 249).

With regard to Ireland Professor Hull describes the pre-Dyassic terrestrial movements as producing "their most powerful and striking effects over the southern and northern districts, while the centre was only partially disturbed and elevated. Over the former districts the [older] beds were forced by lateral pressure to arrange themselves in numerous foldings, which are very evident on a geological map by the bands of Carboniferous beds alternating with those of Old Red Sandstone." . . . "Meanwhile, as the anticlinal ridges were forced into the air, and as the whole of the central area was probably elevated into a land surface, the agents of denudation commenced to wear down the exposed surfaces, and began the process of destruction which has continued so long that only a few isolated remnants of the Coal-measures remain as monuments of the ruin."

The greater part of the materials derived from this Irish land in Dyassic times were doubtless deposited in the neighbouring lake, and some of them still remain in the north-eastern corner of Ireland. From the thickness of the mechanical deposits in this north-western lake, and the rarity of magnesian limestones, we may infer that many streams and rivers ran into it, bringing a constant supply of fresh water and preventing the formation of chemical deposits. The north-eastern lake, on the other hand, seems to have suffered from evaporation and concentration; possibly, also, the waters poured into it contained a larger proportion of salts in solution. At any rate, there are good reasons for regarding the Dyassic dolomites as direct chemical deposits, although the process of precipitation cannot be imitated in our laboratories.

Mr. E. Wilson suggests the following as the probable sequence of events in the north-eastern basin.[1] After

[1] "The Permian Formation of N. E. England, Midland Nat.," vol. iv.

indicating the formation of the basement sands, he says—"After a time the waters would become sufficiently saturated to cause dolomitic materials to be thrown down to some extent, which commingled with the sand and mud, as also with the large supplies of ferrous carbonate likewise brought down by the rivers, would give rise to the blue-coloured plant-bearing dolomitic sandstones and shales of the Marl Slate series. During this stage, mechanical deposition predominated, on the whole, over chemical precipitation. . . . Somewhat suddenly (however) this state of things came to an end.[1] Chemical precipitation now began to predominate, and the formation of the white and yellow Dolomites commenced." In the north this precipitation continued uninterruptedly, but the intercalations of shale and marl in the southern part of the area point to the inflowing of large rivers from the land which then existed over the east of England. It was clearly these southern rivers that brought down the argillaceous material of the Marl Slates and Middle Marls, derived doubtless from a wide surface of Coal-measures then undergoing destruction, while the streams from the west, being smaller but more rapid, may be credited with the introduction of the Yorkshire "quicksands."

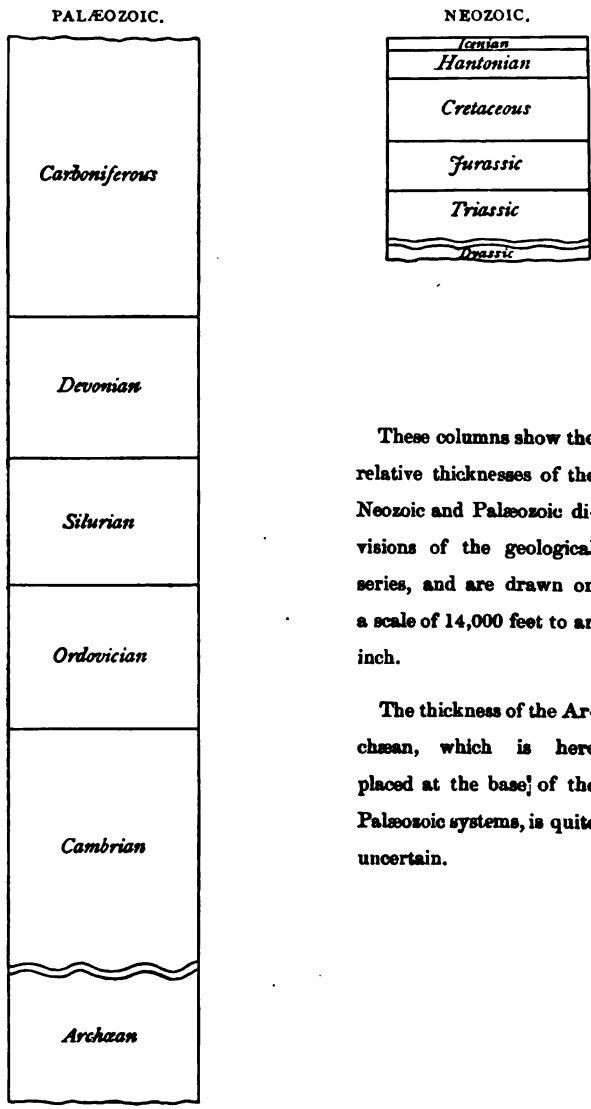
[1] The change, as Mr. Wilson suggests, was probably due to progressive subsidence, which, by diminishing the altitude of the surrounding land, while increasing the area of evaporation, would tend to promote condensation of the lake-waters, and the consequent precipitation of mineral matter in solution.

## CHAPTER VIII.

### NEOZOIC TIME.

WITH the close of the Dyassic period the last remnants of Palæozoic life became extinct in the British area, and when after a long continental period the western and northern parts of Europe were again submerged beneath the sea, the waters were tenanted by a very different set of generic forms. The Palæozoic families of Cystoid and Blastoid Echinoderms, Rugose Corals, Trilobites, and Orthoceratidæ, are no longer represented; their place being taken by the true Echinoidea, Decapod Crustacea, Aporose Corals, Siphonate Gasteropods, and Cephalopods of the Ammonite and Belemnite type: many orders of Reptiles appear for the first time, and the earliest Mammal yet known occurs in the upper beds of the Trias.

Professor E. Forbes considered the difference between the life of the Primary and Secondary rocks to be so much greater than that between the life of the Secondary and Tertiary times, that he proposed to make two divisions only in the life-history of the world—a Palæozoic and a Neozoic—instead of the three, Palæozoic, Mesozoic, and Cœnozoic. There is certainly much to be said in favour of Forbes' view, for though some of the Mesozoic forms become extinct at the close of the Cretaceous period, yet many survive to the present day, and recent discoveries have considerably reduced the magnitude of the gap which was supposed to exist between Secondary and Tertiary strata. The combined thickness of these strata is far less than that of the Palæozoic rocks (see the table on next page), so that if judged by the relative thickness of strata within the limits of the British area, the value of the Palæozoic division would be about four times as great as that of the Neozoic; but the case is altered if the number




These columns show the relative thicknesses of the Neozoic and Palæozoic divisions of the geological series, and are drawn on a scale of 14,000 feet to an inch.

The thickness of the Archæan, which is here placed at the base of the Palæozoic systems, is quite uncertain.

of fossils found in each division are compared, the numbers in 1885 standing thus (according to Mr. Etheridge): Palæozoic species, 4,620; Neozoic species, 8,998, or nearly twice as many.

## The Triassic System.

### Nomenclature and Divisions.

The nomenclature of the Trias of northern Europe is taken from Germany, where the system is more complete than in England, and where it is divisible into three great groups, to which German geologists gave the following names:—

3. Keuper (red marls and sandstones).
2. Muschelkalk (marine limestones).
1. Bunter (red marls and sandstones).

In Britain there is no representative of the Muschelkalk or Middle Trias, the Lower Trias or Bunter being succeeded directly by the Upper or Keuper division; though there are signs of erosion at the junction of the two divisions, and the Keuper beds generally overlap the Bunter and extend far beyond their edges. The classification of the British series as proposed by Professor Hull, and since generally adopted, is as follows:—

| | | |
|---|---|---|
| Keuper. | 3. | Red marls, with rock-salt. |
| | 2. | Red, brown, and white sandstones. |
| | 1. | Conglomerate and breccia (local). |
| Bunter. | 3. | Upper mottled sandstone. |
| | 2. | Pebble beds and conglomerates. |
| | 1. | Lower mottled sandstone and breccia. |

This classification holds good for the whole range of the Trias through England, except in Devon and Somerset, where, as will presently be shown, the succession is somewhat different and apparently more continuous.

It is now admitted, however, that the British and German rocks, being of fluviatile and lacustrine origin, cannot be regarded as the typical deposits of the period, and that for

a complete marine series of Triassic rocks we must go to the Alps. An account of this Alpine Trias will be given after the description of the English and German rocks, and the student must remember that these latter are exceptional, and that the Alpine beds are the normal type of the system.

## LIFE OF THE PERIOD.

**Marine Type.**—The typical fossils of the Trias are of course only to be found where marine beds exist, and it is the Alpine marine series which furnishes the most complete assemblage of Triassic fossils in Europe. This assemblage contains a remarkable mixture of Palæozoic and Mesozoic forms, many of the genera which in more northern districts had become extinct at the close of the Dyassic period still surviving in the Alpine area. Among these may be specially mentioned *Orthoceras*, *Bactrites*, *Goniatites*, *Loxonema*, *Murchisonia*, *Euomphalus*, *Retzia*, *Spirifera*, and *Spiriferina*. These are mingled with such characteristic Mesozoic types as *Ammonites*, *Nerinæa*, *Chemnitzia*, *Lima*, *Ostrea*, *Cardita*, and *Myacites*, and with others which are specially Triassic, such as *Ceratites* (a genus allied to *Ammonites*), the peculiar Gasteropods *Scoliostoma*, *Platystoma*, and *Naticella*, the Lamellibranchs *Halobia* and *Myophoria*, and the Brachiopod *Koninckia* (which is allied to the Palæozoic *Strophalosia*). The Palæozoic forms are, however, decidedly in a minority, and do not amount to more than one-tenth of the whole fauna.

The following are genera which now appear for the first time:—

*Echinoderms.*—Encrinus, Pentacrinus, Cidaris.

*Lamellibranchs.*—Ostrea, Lima, Plicatula, Gervillia, Myophoria, Cardium, Cardita, Myacites, Pleuromya.

*Cephalopoda.*—Ammonites, Belemnites (Aulacoceras).

*Gasteropoda.*—Chemnitzia, Turritella, Turbonilla.

**Lacustrine Type.**—In the lacustrine beds of England and Germany, Plants, Fish, and Reptiles are the principal fossils, and Mollusca of any kind are rare, though species of *Unio* and *Anodon* have been found.

Among Plants the Ferns are represented by the following genera: *Anomopteris, Clathropteris, Sagenopteris, Tæniopteris,* and the Palæozoic *Pecopteris* and *Neuropteris;* Conifers by *Voltzia* and *Albertia;* Cycads by *Zamites, Otozamites, Pterophyllum,* and *Æthophyllum.* The horsetail *Equisetum* also occurs.

Among Fish *Ceratodus,* a genus still living in Australia, is worthy of note; species of *Acrodus, Hybodus, Dipteronotus, Palæoniscus,* and *Pholidophorus* occur.

Of Amphibia, the Labyrinthodonts are still represented by *Labyrinthodon, Mastodonsaurus,* and *Trematosaurus,* but

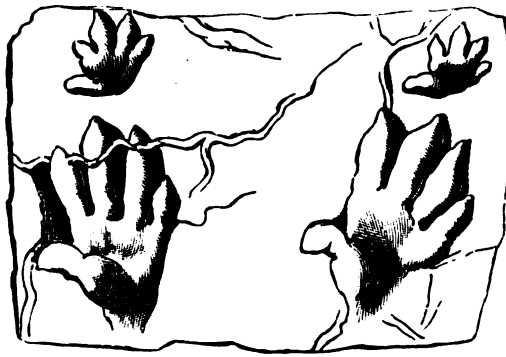


Fig. 51. Foot-marks of Labyrinthodon.

this order does not survive the Triassic period. Their tracks are five-toed, like the rough impress of a man's hand.

Remains of true Reptiles are not uncommon, and include several of the orders which attained their maximum abundance in the succeeding Jurassic period. The Lacertians are represented by *Hyperodapedon, Telerpeton,* and *Rhynchosaurus,* and the Crocodiles by *Stagonolepis* and *Belodon.* Dinosaurs occur for the first time in the forms known as *Palæosaurus, Teratosaurus, Thecodontosaurus,* and *Cladyodon.* These creatures appear to have walked on their hind feet, after the fashion of a kangaroo; and as some of them had only three toes, their footprints greatly resemble those of gigantic three-toed birds, and were supposed for a

long time to have been made by such birds; other genera had four or five toes.

The Trias has also yielded the earliest Mammal which has yet been discovered, namely, a small marsupial allied to the Australian *Myrmecobius*, or Banded Ant-eater, and named *Microlestes*. It is found in the Keuper, or Upper Trias.

## Fossils of the Alpine Trias.

### Lower Trias.[1]

*Lamellibranchs.*—Myophoria costata, Posidonomya Claræ, Pleuromya fassaensis, Avicula venetiana.

*Gasteropoda.*—Naticella costata, Turbo recticostatus.

*Cephalopoda.*—Ceratites Cassianus.

### Middle Trias.

*Echinoderms.*—Encrinus liliiformis, Dadocrinus gracilis.

*Brachiopoda.*—Terebratula vulgaris, Spiriferina Mentzeli, Retzia trigonella, Rhynchonella decurtata.

*Lamellibranchs.*—Lima striata, Gervillia socialis, Halobia Lomelli, Myophoria vulgaris.

*Gasteropoda.*—Natica gregaria.

*Cephalopoda.*—Ceratites binodosus, Ammonites Studeri, Am. dux, Am. luganensis.

### Upper Trias.

*Echinoderms.*—Pentacrinus propinquus, Cidaris dorsata.

*Brachiopoda.*—Terebratula indistincta, Koninckia Leonhardi.

*Lamellibranchs.*—Cardita crenata, Halobia rugosa, Nucula lineata, Cassianella grypheata.

*Gasteropoda.*—Natica Meriani, Chemnitzia Escheri, Monodonta cassiana, Gyroporella annulata.

*Cephalopoda.*—Ammonites floridus, Am. aon, Am. jarbas, Orthoceras elegans, O. reticulatum, Bactrites nudatus, Aulacoceras alveolare.

[1] Marine fossils only occur in the upper part of the Alpine Bunter.

## Fossils of the English and German Trias.

### Buntee.

*Mollusca.*—Myophoria costata (in upper marls of Germany).

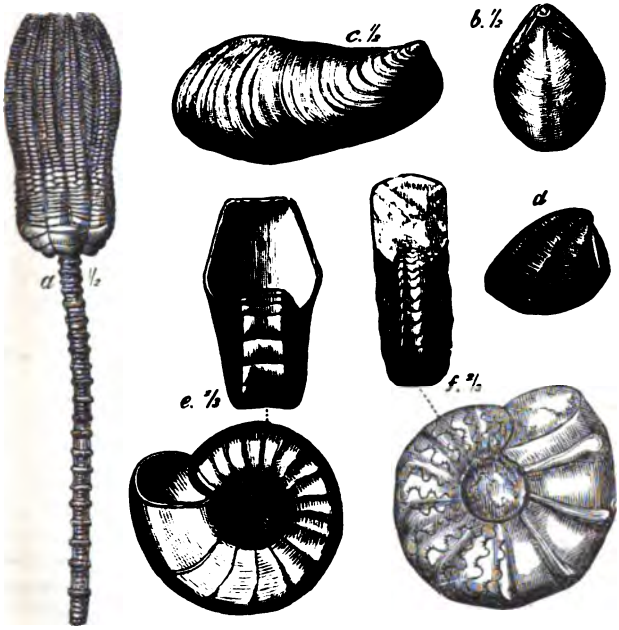



Fig. 52. Muschelkalk Fossils.

*a.* Encrinus liliiformis.
*b.* Terebratula vulgaris.
*c.* Gervillia socialis.
*d.* Myophoria vulgaris.
*e.* Nautilus hexagonalis.
*f.* Ceratites nodosus.

*Plants.*—Equisetum arenaceum, Albertia elliptica, Æthophyllum speciosum.

*Reptiles.*—Placodus impressus, Nothosaurus Schimperi.

### Muschelkalk.

*Echinoderms.*—Encrinus liliiformis, Aspidura loricata.
*Brachiopoda.*—Terebratula vulgaris.
*Lamellibranchs.*—Myophoria vulgaris, Lima striata, Pecten discites, Gervillia socialis.
*Gasteropoda.*—Turritella reallata.
*Cephalopoda.*—Nautilus bidorsatus, Ceratites binodosus.
*Fish.*—Acrodus Gaillardoti, Ceratodus heteromorphus, Hybodus major.

### Keuper.

*Plants.*—Equisetum columnare, Pterophyllum Jageri, Voltzia heterophylla, Tæniopteris vittata.
*Crustacea.*—Estheria minuta.
*Fish.*—Palæoniscus superstes, Dipteronotus cyphus, Acrodus minimus, Hybodus Keuperi.
*Reptiles.*—Labyrinthodon giganteum, Cladyodon Lloydii, Hyperodapedon Gordoni, Telerpeton elginense.
*Mammalia.*—Microlestes antiquus.

## Rocks of the British Islands.

### *Range and Relation to Rocks below.*

Triassic rocks commence on the south coast between Tor Bay and Teignmouth, where they form five cliffs; they extend eastward past the mouths of the rivers Exe and Otter as far as Sidmouth and Axmouth, where they are covered by Cretaceous rocks. Inland they extend northward through Devon and Somerset in a band of varying width, which sends tongues or prolongations westward across the valley of the Exe into central Devon; and in Somerset the strike of the beds curves round to the north-west, and passes over the edges of the Devonian rocks to the coast of the Bristol Channel at Minehead and Porlock Bay. The upper beds also occur near Penarth in Glamorganshire; so it is clear that the Trias had a considerable extension westward down the Bristol Channel.

In North Somerset the upper beds of the Trias encircle the Mendip Hills, and occur in patches over the area of the Bristol coalfield. In the Severn valley it is overlapped by the Trias, but emerges again to the west of Gloucester, and runs northward through Worcestershire between the Malverns and the valley of the Severn; the width of its area increasing till it spreads out over large parts of Stafford, Warwick, Leicester, and South Derby, interrupted only by island-like patches of the older rocks, which rise up from beneath it.

Of its eastward subterranean extension we know that it thins out rapidly to the south-east against the ridge of Palæozoic rocks which underlies Herts and Essex. Borings near Northampton found only from 60 to 70 feet of Trias, while at Ware and Turnford it is entirely absent. South of London, however (at Richmond and elsewhere), mottled sandstones resembling those of the Trias have been found from 1,100 to 1,200 feet below the surface. It was also pierced at Burford in Oxfordshire, where its thickness is 424 feet, and it rests on Coal-measures at 1,084 feet.

North of this great central expansion the Triassic area is divided into an eastern and a western fork by the range of the Pennine Hills, which were in existence before its formation; one tract extends through Nottingham and Yorkshire, forming a broad plain between the Magnesian Limestone and the Lias as far as York; thence it narrows, but runs up the valley of the Ouse and across that of the Tees to the coast at and south of Hartlepool. The other tract extends from Staffordshire through Shropshire, Cheshire, and Lancashire to the shores of Morecambe Bay; while outlying tracts of Trias occur in North Wales (Vale of Clwyd), and along the shores of the Solway Forth, extending inland for some distance up the Eden valley.

In Scotland there are small tracts in Dumfriesshire, some scattered patches in the Western Isles, and a tract on the south shore of Moray Firth (Elgin and Ross).

In Ireland Trias is found only in Ulster (Antrim, &c.), and does not occupy any large area at the surface, though it probably extends beneath the chalk and basalt of the former county.

The Triassic strata are everywhere unconformable to the

rocks on which they rest; they extend far and wide beyond the edges of the Dyassic beds, and run up many of our wider valleys as if the principal hill-ranges of England were then already in existence, as indeed they doubtless were. The Coal-measures and older Palæozoic rocks had been bent into troughs, basins, and ridges, and had suffered enormously from erosion and detrition before the Triassic beds were deposited upon them, so that in most parts of the country these beds rest upon a surface of erosion which had been previously formed across the tilted edges of the Palæozoic rocks.

The stratigraphical relations of the Palæozoic and Neozoic strata are of the greatest importance to the student of British geology, and fig. 53 has been drawn with the special object of illustrating these relations. Fig. 53 is a diagrammatic section from the valley of the Severn through the counties of Gloucester, Oxford, Buckingham, and Hertford to the valley of the Lea at Ware. It shows the succession of the Neozoic rocks from the Trias to the Chalk, and the manner in which they rest upon the floor of Palæozoic rocks which lies beneath. The depth of this floor from the surface of the ground is known at two points along the line of section, namely, at Burford and Ware, Coal-measures being found at the former place, and Silurian rocks at the latter below the Neozoic strata; but the depth of the floor elsewhere is quite uncertain, neither can we tell what group of rocks would be struck at any particular locality; the flexures shown in the diagram are purely theoretical, and are only inserted to show the general way in which the Palæozoic rocks may be supposed to lie. It is an ascertained fact, however, that the Jurassic rocks thin out eastward, and are entirely absent beneath the Gault in Hertfordshire.

In the counties of Devon, Somerset, and Gloucester the gap, unconformity, and divergence of strike are very great, the Devonian and Carboniferous rocks striking roughly from west to east, while the Triassic beds pass across and over their edges in a general N.N.E. direction.

In Worcestershire the Trias rests in different places on all older rocks, from the Malvern Cambrians to the Dyas inclusive; where it abuts against the Dyassic outlier of the

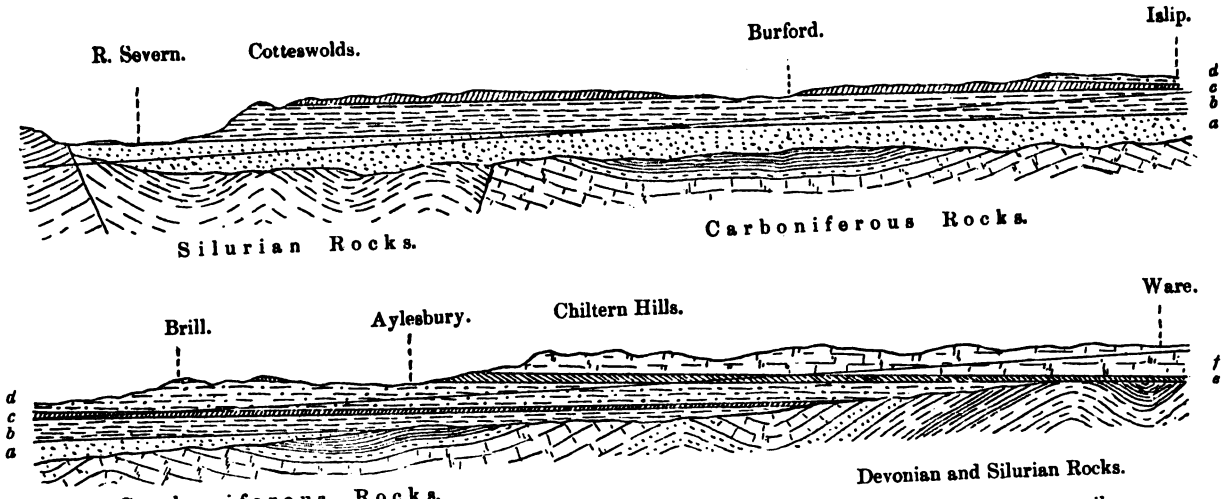



Fig. 53. Diagram-section from the Valley of the Severn to that of the Lea at Ware. Distance about 108 miles.

Cretaceous. { *f.* Chalk. *e.* Gault.

*d.* Kimeridge and Oxford Clays.
*c.* Oolites (Middle Jurassic).

*b.* Lias.
*a.* Trias.

Abberley Hills, the boundary line seems to be of the nature of a cliff or steep shore-margin, and it is clear from the position of this and other Dyas outliers that the latter formation had undergone extensive disturbance and destruction before the Triassic period.

In the Midland counties the Trias rests similarly upon everything quite unconformably, overstepping the Dyassic rocks, and wrapping round the exposed portions of the Staffordshire, Warwickshire, and Leicestershire coalfields. Most of the dislocations which are so numerous in these coalfields were produced before the Triassic period, and the Trias rests on the tilted and eroded edges of the Carboniferous rocks, running up into the ancient valleys and hollows. In Shropshire, although the dip of the Dyas and Trias is almost identical in direction and amount, yet Mr. Hull describes the latter as really unconformable to the former, and as passing transgressively over the edges of the component beds.

In Notts and Yorkshire, where the Trias overlies the Magnesian Limestone, there is a similar discordance, for though they both dip in the same direction, and in single sections appear to be conformable, yet in reality the Trias is transgressive across the Dyas as it passes southward from Yorkshire, overstepping first the Upper Marls, then the Upper Limestone (near Worksop), next the Middle Marls (near Nottingham), and, finally, to the west of Nottingham, passing across the Lower Limestone on to the Coal-measures. There is therefore an unconformity, though it is not nearly so great as that between the Dyas and the Carboniferous rocks.

In Cheshire and Lancashire the Trias is spread unconformably over the Dyas, Coal-measures, Millstone Grit, and Yoredale rocks. In Scotland it rests on Silurian and Old Red Sandstone. In Ireland the break and unconformity is equally great (see vol. i. "Physical Geology," p. 389).

### *England.*

**Southern District.**—In Devonshire the Trias occupies the coast-line from Babbicombe (near Torquay) as far as

Axmouth, the older beds lying to the west and the newer to the east. According to Mr. W. A. E. Ussher,[1] who has carefully surveyed this coast-section and the country behind it, the beds seen may be grouped as follows:—

| | | Feet. |
|---|---|---|
| Upper. | 5. Upper marls | 1,000 |
| | 4. Upper sandstones | 460 |
| | 3. Conglomerates | 80 |
| Lower. | 2. Lower marls | 460 |
| | 1. Sandstones and breccias | 1,000[2] |

He describes this series as quite continuous, and regards the Lower Marls (2) as beds of passage between the Bunter (1) and the Keuper, to which he refers the higher members (3, 4, and 5); but as similar marls occur above the Bunter sandstones in Germany, stronger evidence must be obtained before this view can be accepted.

The basement breccias are chiefly developed in the south-west, near Teignmouth, and consist of blocks and pebbles of various sizes, many large enough to be called boulders: these fragments have mostly been derived from the Devonian and Carboniferous rocks which lie to the westward, and which formed the coast-line of the period. The upper beds of breccia are not so coarse, and are irregularly interbedded with sandstones and marls.

The Lower Marls are variegated red and grey, and contain several beds of sandstone; they occupy the slopes and the low ground below the ridge made by the overlying beds.

The pebble-beds which succeed are sometimes loose, and sometimes compacted into conglomerate; the pebbles are principally limestone (Devonian) and sandstone (Devonian and Carboniferous), but at Budleigh Salterton and Burlescombe the pebbles are sandstones and quartzites, containing Silurian and Devonian fossils; these quartzites have probably been derived from the southward, for rocks with similar fossils occur in Normandy.

[1] "Quart. Journ. Geol. Soc.," vol. xxxii. p. 370.

[2] This is the apparent thickness, but as there is much oblique bedding the real thickness is probably much less.

The Upper Sandstones are red, often mottled and streaked with grey, and are chiefly remarkable as yielding remains of reptiles, *Labyrinthodon* and *Hyperodapedon*.[1]

The Upper Marls are red and variegated; they are exposed on the coast at Seaton, Sidmouth, and Axmouth, stretching inland by Ottery and Honiton, and through the vale of Taunton to Bridgwater, and thence north-westerly to Watchet on the Bristol Channel. Here in north-west Somerset the lower stages are wanting, and only the Keuper division remains.

The Keuper Marls extend over a far wider area than any of the lower beds; and in North Somerset, Gloucester, and Glamorgan, none but beds of this stage are to be found. Around the Mendip Hills, and in the Bristol district, wherever the old Palæozoic surface is exposed, the basement beds of the Keuper are conglomerates of a peculiar kind. They consist mainly of pebbles of Carboniferous Limestone, the majority as large as a hen's egg, but ranging up to boulders of two or three feet diameter; these are held together by a calcareous cement or matrix, generally dolomitic, so that the beds are known as the Dolomitic Conglomerate; calcareous sandstones are sometimes associated with it, and it passes beneath the red (Keuper) marls which form the Triassic tracts here shown on a geological map.

The conglomerates are not, however, as a whole older than the marls, for they occur at all horizons along the margin of that deposit and dovetail into it (see fig. 54). They are in fact the ancient beaches formed during the gradual submergence of the area in Upper Triassic times.

The same beds occur in Glamorganshire, near Cardiff, and west of Newton Nottage. At the head of the estuary of the Severn, the Trias is overlapped by the Lias, but sets in again north of Newnham, and west of Gloucester.

**Midland Districts.**—In Worcestershire the Keuper marls thicken rapidly northwards, and the lower stages of this division come in gradually on the west, but the Bunter sandstones do not appear till the northern extremity of the Abberley Hills is reached, where they set in and strike

[1] "Quart. Journ. Geol. Soc.," vol. xxv. p. 146, and vol. xl. p. 257.

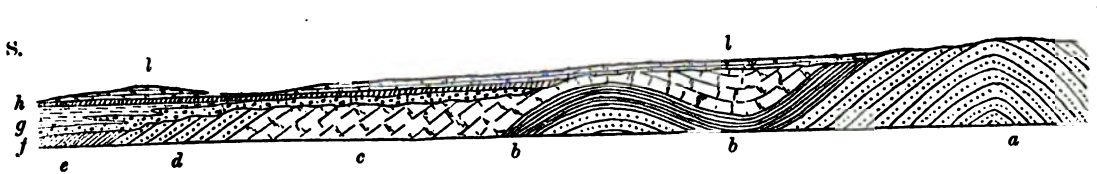



Fig. 54. Diagram-section on the south side of the Mendip Hills. (After De la Beche and H. B. Woodward.)

Neozoic.
- *l.* Lias Limestone.
- *h.* Rhætic Beds.
- *g.* Keuper Marls.
- *f.* Dolomitic Conglomerate.

Palæozoic.
- *e.* Coal-Measures.
- *d.* Millstone Grit.
- *c.* Carboniferous Limestone.
- *b.* Lower Limestone Shale.
- *a.* Old Red Sandstone.

north-east below the escarpment of the Lower Keuper Sandstones. A traverse from Droitwich, through Kidderminster, would pass over the following succession of beds:—

| | | Feet. |
|---|---|---|
| Keuper. | 5. Red marls, with rock-salt and gypsum | 500 |
| | 4. Red and yellow sandstones, with bands of conglomerate and a basement breccia of grit and quartzite pebbles | 400 |
| Bunter. | 3. Bright red sandstone, mottled with yellow and white | 300 |
| | 2. Brownish red sandstone, with quartzite pebbles, often becoming a conglomerate | 300 |
| | 2. Breccia of angular fragments of older rocks | 60 |
| | 1. Bright red and yellow sandstones | 60 |
| | | 1,620 |

The breccia of No. 2 rests on an eroded and waterworn surface of No. 1, and the basement breccia of the Keuper probably rests in a similar manner on the surface of No. 3. Both indicate the introduction of powerful currents over the area of deposition. The Keuper sandstones (No. 4) are quarried in many places for building stone. The brine-springs of Droitwich and Shirleywich are derived from the beds of rock-salt that occur in the red marls.

With minor variations in character and thickness the series above described continues through the counties of Stafford and Salop.

It is noteworthy, however, that the Lower Mottled Sandstone thins out eastward against the South Stafford coal-field, and northward against the Dyas of Cheswardine and Darlaston, the Pebble Beds resting directly on the older rocks of these districts. In North Staffordshire the Upper Mottled Sandstone also thins out, so that in the Alton district and in Derbyshire, about Ashbourne, the hard white conglomerate at the base of the Keuper rests upon the soft pebbly sandstone of the middle division of the Bunter.

This conglomerate is about forty feet thick, and passes up into white freestones with bands of marl (150 feet). The Alton district is traversed by several faults ranging east and west, which produce repetitions of the conglomerate escarpment.

In Warwick the Bunter division is only found near the Birmingham and Sutton coalfield; it comprises some 250 feet of the Pebble Beds and Upper Mottled Sandstone. In Leicestershire the Pebble Beds alone remain, and they also thin out along a line passing across the centre of the coalfield, east of which the Lower Keuper Sandstone rests directly on the Coal-measures, and is banked against the Cambrians at the north end of Charnwood Forest.

The base of the Keuper here is usually a band of red clay (with nodules of hæmatite), on which rests a bed of quartzose gravel, becoming a breccia of slate and porphyry as it approaches the Charnwood area. This is overlain by white sandstones (Waterstones) with bands of red shale, sun-cracked and ripple-marked. Total thickness of Lower Keuper 100 to 150 feet.

The Upper Keuper consists of red marls with occasional beds of white micaceous sandstone, and a thick bed of gypsum at Chellaston. Its thickness is 600 feet. It wraps round the south side of the Charnwood area, overlapping the Waterstones.

**Nottingham and York.**—Near Nottingham the Bunter beds again make their appearance from beneath the Keuper, and range northward in a continuous strip between the latter and the Dyas. The Upper Mottled Sandstone is, however, absent throughout this eastern area, and the whole of the Bunter appears to thin out and disappear in Yorkshire. Near Nottingham the succession is as follows:—

| | | Feet. |
|---|---|---|
| Keuper. | Red marls, with much gypsum, and beds of sandstone near the base | 600 |
| | Waterstones, with pebbly or conglomeratic base | |
| | White sand and pebble beds | |
| Bunter. | Yellow sandstones, coarse and pebbly | 300 |
| | Lower Mottled Sandstone | 25 to 100 |

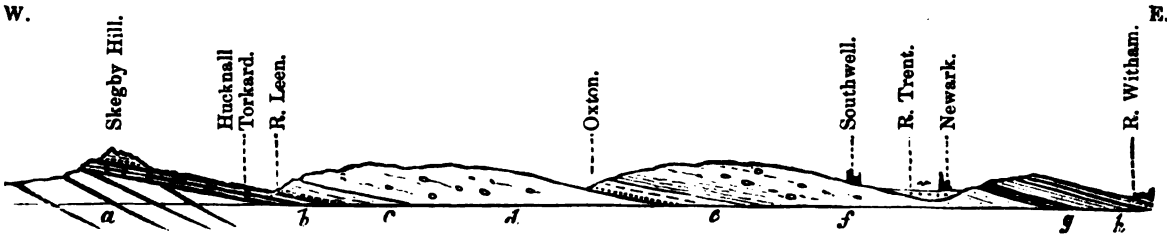



Fig. 55. Section through South Notts, from the R. Erewash to the R. Witham. Distance about 22 miles.

*v.* Alluvium.
*h.* Lower Lias.
*g.* Rhætic Beds.
*f.* Upper Keuper Marl.
*e.* Lower Keuper Sandstone.
*d.* Bunter Conglomerate.
*c.* Lower Bunter Sandstone.
*b.* Permian Rocks.
*a.* Coal-Measures.

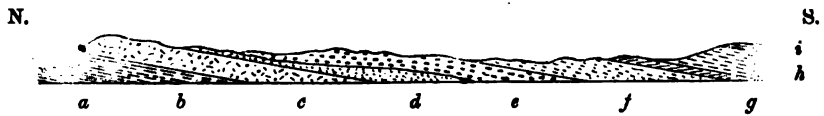



Fig. 56. Section from the Clent Hills in Staffordshire to Turret Hill in Worcestershire. Distance about 13 miles.

*i.* Lower Lias.
*h.* Keuper Marls.
*g.* Keuper Sandstone.
*f.* Soft Mottled Sandstone.
*e.* Bunter Pebble Beds.
*d.* Soft Red Sandstone.
*c.* Breccia (Dyas).
*b.* Red Marls.
*a.* Coal-Measures.

The Lower Bunter Sandstone is of a bright red or orange colour; it is traceable into Yorkshire, and is believed to extend as far as Ripon, beyond which it is either absent or is indistinguishable from the Keuper sandstones which there overlie it.

The Bunter Pebble Beds form the rock on which Nottingham Castle stands, where they consist of a coarse yellowish sandstone full of quartzite pebbles. They range northward through Sherwood Forest, by Worksop, Tickhill, and Doncaster, but it is doubtful whether they extend far beyond the last place. The sandstone passes sometimes into loose red and yellow pebbly sands, and sometimes into a

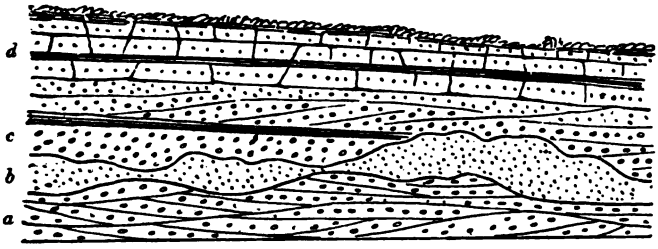



Fig. 57. Junction of Keuper and Bunter near Nottingham.
*d*. Waterstones. *b*. White Sand.
*c*. Conglomerate. *a*. Pebble Beds.

hard conglomerate. The pebbles are everywhere the same, principally quartzite and quartz, with a few fragments of soft sandstone and black chert.

The basement bed of the Keuper division near Nottingham is an irregular deposit of white sand, which rests on an eroded surface of the Bunter Pebble Beds (see fig. 57), and varies from a few inches to many feet in thickness. Mr. J. Shipman has recently described certain pebbly sandstones more than 100 feet thick, which he regards as representing this deposit.

The Waterstones which succeed generally have a pebbly or conglomeratic bed at the base, and this rests sometimes on the white sand deposit, and sometimes directly on the

Bunter, but always on an eroded surface, so that it seems to be unconformable to the beds below. The pebbles are chiefly quartz and quartzite, but Mr. Shipman has detected fragments of trap, slate, chert, and magnesian limestone. The Waterstones themselves consist of soft brown sandstones interstratified with red marls, which cause plentiful springs by throwing out the water collected in the sandstones. Ripple-marks and sun-cracks are frequent in these beds.

There is no marked line of division between the Waterstones and the Keuper Marls; the marl bands become thicker, but still contain beds of sandstone in the lower 150 feet, though these sandstones are harder and generally white or bluish-grey; gypsum occurs in the marls, and the higher beds are chiefly marl with sheets and nodules of gypsum.

In Yorkshire the Keuper appears to be some 1,500 feet thick, and is only capable of division into an upper red marl group, about 300 feet thick, and a lower series of red and white sandstones interstratified with red marls and with beds of salt and gypsum (1,200 feet). The salt rock of the Middlesborough borings is 100 feet thick, and lies at the very base, resting on magnesian limestone (see p. 239).

**Cheshire and Lancashire.** — The Trias of these counties is a continuation of the Shropshire series, but attains a greater development, the average thickness of the several stages being as follows:—

| | | Feet. |
|---|---|---|
| Keuper. | Marls and Upper Sandstone | 1,500 |
| | Lower Sandstones (Waterstones) | 400 |
| Bunter. | Upper Mottled Sandstone | 500 |
| | Pebble Beds | 600 |
| | Lower Mottled Sandstone | 400 |
| | | 3,400 |

*Bunter.*—Near Chester the lowest beds are seen to rest on the purple shales and sandstones of the Millstone Grit, the basement being a dark purple breccia (10 feet thick), passing up into coarse sandstones, soft, and coloured red,

yellow, and white. This division ranges northward to the Mersey, and then eastward along the south border of the Lancashire coalfield, but thins in that direction, and does not occur at Manchester or Stockport.

The Pebble Beds are well seen at Holt, on the river Dee, where their base is a breccia, succeeded by soft red-streaked sandstone overlain by pebbly sandstone, the whole series resembling that at Bridgnorth. Near Liverpool and St. Helens they consist of red-brown pebbly sandstones not less than 600 feet thick, and eastward by Wigan, Manchester, and Stockport, they overlap the Lower Mottled Sandstone, so as to rest on the Dyassic and Carboniferous rocks.

The Upper Mottled Sandstone ranges along the flanks of the Peckforton Hills, through Delamere Forest, to Runcorn and Warrington, and thence through West Lancashire by Liverpool and Ormskirk. Its only peculiarity is, that while the lower part is of the usual red colour streaked with white, the upper part is of bright yellow.

The whole of the Bunter is said to thin out north of Ormskirk, and to be absent at Preston, just as it disappears near Ripon on the eastern side of the Pennine Chain.

Sandstones of Bunter age border the north coast of Flintshire, and run up the valley of the Clwyd as far as Ruthin.

*Keuper.*—The base of the Keuper division is always pebbly, and sometimes (as at Peckforton) becomes a hard calcareous conglomerate. This is succeeded by hard red, yellow, and white sandstones (200 feet thick, and quarried for building stone); above which are the Waterstones—brown micaceous flagstones, with red and grey shales at their base (together 200 feet in Delamere Forest and at Liverpool).

The Peckforton Hills rise to heights of 800 and 900 feet, and a series of strike-faults has led to the development of a succession of nearly parallel escarpments, the western slopes of which consist of the soft Bunter sandstone, while the rock forming their summits is the hard basement conglomerate of the Keuper.

Near Liverpool (as at Scarth Hill) the Keuper is found to rest on a deeply eroded surface of the Bunter sandstone,

and a section on the railway near Ormskirk shows actual unconformity, the coarse pebbly sandstone passing across the edges of the lower beds from west to east (see fig. 58). At Preston the Keuper rests on Carboniferous rocks.

The upper red and grey marls contain, as elsewhere, layers of gypsum and beds of rock-salt from 70 to 100 feet thick. These are worked by shafts and pits at Northwich, but elsewhere it is obtained in the form of brine from borings, the water percolating through the beds dissolving the salt and being pumped up the bore-hole. The thickness of these saliferous marls in Cheshire is very great, being estimated by Professor Hull at about 3,000 feet. Their most northerly point of occurrence in Lancashire is Fleetwood, near which place a boring

Fig. 58. Cutting on the railway near Ormskirk.

*d.* Keuper sandstone. *b.* Dull red sandstone.
*c.* Yellow sands. *a.* Mottled sandstone.

passed through red marls (258 feet) and rock-salt with layers of shale for 266 feet.

**The Carlisle Basin.**—This includes the country from the neighbourhood of Carlisle westwards on either side of the Solway Firth, and is therefore partly in England and partly in Scotland. The Triassic beds here are different from those in Lancashire, and the succession is given by Mr. T. V. Holmes as follows:—

| | | Feet. |
|---|---|---|
| Upper. | Stanwix marls . . . | ? 100 |
| | Kirklinton sandstone . . | 500 |
| Lower. | Gypseous shales . . . | 700 |
| | ? St. Bees sandstone . . | 1500 |

*Lower Beds.*—The possibility of the St. Bees sandstone being of Triassic age was mentioned at p. 246. It forms the outer rim of the Carlisle Basin. The gypseous shales have been proved in several borings, but are not seen at the surface, and only occur in the south-western half of

the basin. Mr. Holmes writes,[1]—"The St. Bees sandstone and gypseous shales had evidently been planed down by denudation before the Kirklinton sandstone was deposited above them. This denudation appears to have been greater toward the north-east end of the basin than about the centre; thus, while at Great Orton 132 feet of the gypseous shales were left, at Netherby not only were these shales swept away, but much of the St. Bees sandstone also."

*Upper Beds.*—The Kirklinton sandstone consists of bright red current-bedded sandstone in the lower part, but the higher beds are chiefly white and grey sandstones.

The Stanwix marls are only found in the centre of the basin about Harker and Blackford, between the rivers Lyne and Eden; they appear to be slightly unconformable to the Kirklinton sandstone, resting partly on the red portion, and partly on the white beds of that formation. They are red and grey in colour, and are clearly the representatives of the Keuper marls. Their surface is obscured by drift, and their exact thickness is not known, but is probably less than 100 feet.

These upper beds of the Carlisle Basin may be compared with the Keuper division in Yorkshire, the succession being similar—red and white sandstones at the base, overlain by an unusually small thickness of marl.

### *Scotland.*

**Western Isles.**—Conglomerates, sandstones, and marls referable to the Trias occur below the Jurassic series in Skye and some of the Western Isles, as well as at Gruinard Bay, Ardnamurchan, and Morvern on the mainland.

The following account is taken from Professor Judd's description.[2] The materials forming the breccias, conglomerates, and coarser sandstones have evidently been derived from the older rocks on which these strata repose, usually either the Torridon sandstone or some member of

[1] "Water Supply in the Carlisle Basin, Trans. Camb. Assoc.," No. viii. p. 21.

[2] "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 686.

the Highland gneissic series. A special feature in the Triassic rocks of this region is the abundance of calcareous matter which enters into their composition. Fragments of compact limestone (? Durness limestone) abound in the coarser beds; the sandstones often pass into calcareous grits, and bands of cornstone are not unfrequent, while all the beds are frequently traversed by veins of calcspar. As a rule, the breccias and conglomerates prevail in the lower part of the series; sandstones, marls, and limestones in the upper part, but everywhere the succession of beds is very irregular and inconstant. At Gruinard Bay the total thickness exceeds 1,000 feet; at Raasay it is probably less than 500 feet, though the general succession is the same; at Lussay, in Skye, it is reduced to a few feet, but southward, in parts of Mull and Morvern, it is probably not less than 1,200 feet thick.

The following is the succession at Gruinard Bay:—

| | Feet. |
|---|---|
| Soft reddish argillaceous and sandy beds, with bands of hard white and greenish sandstone . . . . . | 200 |
| Red and variegated marls, with thin beds of sandstone and cornstone. . . | 200 |
| Red argillaceous sandstones and conglomerates, alternating in the lower part with masses of coarse breccia-conglomerate . . . . . | 500 |

In Morvern the concretionary limestones which occur in the marly division are sometimes of considerable thickness, and are very much like the cherty rock of Stotfield on the north-east coast. No fossils have been found, except some casts of bivalves (? *Cyrena*) in sandstone at Ardtornish.

**North-East Coast.**—Small tracts of Trias are also found in Elgin on the south side of the Moray Firth, and near Dunrobin Castle in Sutherland. The lowest beds are pale yellow ripple-marked sandstones, with ripple-marks, sun-cracks, and reptile-tracks; they have yielded bones of *Stagonolepis*, *Hyperodapedon*, and *Telerpeton*, and teeth of

the fish *Ceratodus*. Above these sandstones is a curious hard silicious limestone or chert, known as the Stotfield Rock and about thirty feet thick, but destitute of fossils.

### *Ireland.*

Triassic rocks are only found in the north-eastern part of Ireland, and lie in an oval-shaped basin excavated out of the Palæozoic rocks, but only small tracts are exposed, the greater portion of the area being concealed by newer rocks. A small outlying tract of Trias occurs near Kingscourt, co. Cavan, about thirty miles south of the main outcrop in Tyrone; this is specially interesting as proving that the Trias had formerly a southern extension in this direction.

On the borders of Tyrone and Armagh there are bright red sandstones, belonging, it is supposed, to the Bunter, but no good sections are known. They pass eastward beneath the Tertiary Basalt of Portadown.

The largest area of Trias occurs in the valley of the Lagan, and extends from Lurgan to Belfast, and thence along the northern shore of Belfast Lough, as far as Ballycastle; an arm of it also passes across from Belfast to the northern shore of Strangford Lough. Rock-salt is found near Carrickfergus, and the general succession in this tract is as follows[1]:—

| | | Feet. |
|---|---|---|
| Keuper. | Red marls, with gypsum . . . | 800 |
| | Rock-salt and blue clays . . . | 150 |
| | Brownish sandstones . perhaps | 20 |
| Bunter. | Soft red and yellow sandstones . Red sandstones and yellow shales | 1,000 |

Narrow tracts of Trias are found in the north of Tyrone and in Londonderry, but only a small thickness is exposed before they pass beneath the Cretaceous series.

[1] Kinahan, "Geology of Ireland," p. 137.

## Volcanic Rocks.

Devonshire is the only part of Britain where contemporaneous lavas occur in the Trias. They were described by Sir H. De la Beche fifty years ago, and more recently by Mr. W. Vicary.[1] They occur in the Lower Sandstone group, and the lavas are peculiar, most of them consisting of plagioclase, orthoclase, an abundance of mica, some hornblende, and much hæmatite; in colour they are dark red or purple, and may be termed mica-traps or minettes. Killerton Park is described as having the aspect of a volcanic centre, the lava becoming scoriaceous and ashy in the outer portions toward Budlake and Silverton. De la Beche describes the Tiverton area in similar terms, and states that the dark micaceous lava is covered by volcanic detritus containing angular blocks, some of which weigh as much as a ton. Knowle Hill consists of a compact porphyritic lava which may have been the centre whence came the lavas and ashes that are found at Pocombe and Northernhay. Other large volcanic masses occur near Haldon, North Fawton, and Crediton, some of the lava-flows being highly vesicular, and others exceedingly compact.

## Continental Equivalents.

**Germany.**—The German Trias falls naturally into three great groups or series, as already mentioned (p. 259).

1. *Bunter.*—This is essentially a sandstone series, as in England. Its lowest beds are dark red, thin-bedded, or shaly sandstones (Bunter-schiefer), which were regarded by Murchison as the uppermost members of the Permian (Dyas), but Geinitz shows that they lie unconformably on the Zechstein, and pass up into the true Bunter.[2] The rest of the Lower Bunter consists of red and variegated sandstones and marls, with beds of gypsum and dolomite. The

[1] "Trans. Dev. Assoc. for Advance. of Science, Lit., and Art," 1865.
[2] See Irving in "Quart. Journ. Geol. Soc.," 1884, p. 389.

middle beds are coarse sandstones, and the highest are red and green marls with marine shells (*Myophoria costata*).

2. *Muschelkalk.*—This is a limestone series from 600 to 1,000 feet in thickness, and divisible into three stages as follows, in descending order:—

*c.* Thin-bedded limestones and dolomites (Wellenkalk), with a few fossils (*Myophoria orbicularis, Encrinus liliiformis*).
*b.* Marls with anhydrite and rock-salt; no fossils except bones of Reptiles.
*a.* Bedded limestones, yellowish or reddish grey, full of fossils (see p. 263), some beds being wholly made up of Crinoid stems.

In the Vosges country west of the Rhine, some of the limestones are replaced by sandstones and marls, the whole series becoming thinner and thinner, till at last (at the Attert) it has dwindled to a mere band only four feet thick. This westerly attenuation of the Muschelkalk explains its entire absence in England.

3. *Keuper.*—The basement group of this series consists of dark grey shales and sandstones with thin beds of earthy coal (Kohlenkeuper); some of the beds contain marine shells (*Gervillia, Lingula*), others are crowded with the small crustacean *Estheria minuta*. This group is about 250 feet thick, and is succeeded by red and green marls with thin sandstones exactly like the mass of the Keuper in England, and having a maximum thickness of 1,000 feet.

**Alpine Region.**—The Trias of the Alps is a marine formation, and gives us a much more complete record of the period and the marine creatures which then existed. It has no great thickness in the Central Alps, but attains a great development in the well-known Dolomite Mountains of the South Tyrol and Carnic Alps, and also in the Vorarlberg, North Tyrol, Salzburg, and Bavaria, on the northern side of the main crystalline axis. The following are the successive stages in these northern and southern districts respectively, the total thickness in the former being about 6,000 feet:—

*Upper Trias.*

| *Southern Area.* | *Northern Area.* |
|---|---|
| Raible Beds; shales and marls, with many fossils, *Cardita subcrenata*, *Halobia rugosa*, and *Am. floridus*. | *Cardita crenata* Beds; shales, limestones, and sandstones, with *C. crenata*, *H. rugosa*, *A. floridus*. |
| The Schlern Dolomite; more than 3,000 feet thick, but with few fossils. | The Wetterstein; white limestones, with *Ammonites*, *Orthoceras*, and many corals. |
| St. Cassian Beds, volcanic ash with marly bands full of fossils, *Am. aon*, *Cidaris dorsata*. | Marls with St. Cassian fossils at base of the Wetterstein. |
| | Red "Plattenkalk." |

*Middle Trias.*

| | |
|---|---|
| Wengen Beds; dark limestones and shales with *Halobia Lomelli*. | Partnach beds; shales, and limestones, with plants. |
| Mendola Dolomite. | Virgloria limestone in two stages as below. |
| | *b*. Cephalopod beds, *Am. Studeri* and *Ceratites binodosus*. |
| | *a*. Brachiopod beds, *Retzia trigonella*, *Spiriferina Mentzeli*. |

*Lower Trias* (*Bunter*).

| | |
|---|---|
| Campil shales and limestones, with *Gervillia costata*, *Pleuromya fassaensis* and *Naticella costata*. | Guttenstein Beds; dark limestones, with red and green shales. |
| Gröden sandstones, red and white, with *Voltzia* and *Æthophyllum*. | Werfen Beds; red shales and sandstones, with gypsum and rock-salt. |

## Physical Geography.

It is uncertain whether the pre-Triassic elevation and tilting of the Dyassic rocks involved the partial desiccation of the Dyassic lakes, and the upheaval of the greater portion of their area into dry land. This may have been the case, and the great change which took place in the fauna and flora certainly seems to indicate the lapse of a long period of time; but if so, the upheaval must have been a bodily elevation of the Dyassic continent around these lakes, and the subsequent depression must have been similarly equable and co-extensive, since the lowermost Triassic beds occupy nearly the same areas as the Dyassic.

Professor Ramsay compares the geographical conditions of northern Europe during Triassic times to those of central Asia at the present time, where from the Caspian Sea for 3,000 miles to the eastward and far south toward the Himmalayah there is a comparatively rainless district in which all the lakes are salt, except those which have an outlet to some lower lake.

The unrepresented period of time between the epochs of the Dyas and Trias may have been more especially a rainless one, during which the European lakes shrank to a minimum; geographical changes may then have increased the rainfall, causing the lakes to fill again and new deposits to be formed in them, for the area of the lake-basins would always vary with the annual amount of rainfall, and with the extent to which communication was opened up from time to time with the outside sea. We know that open sea existed in southern Europe, the Alps not then existing as mountains), and that at one time submergence allowed it to spread northward over Germany, causing the intercalation of the marine Muschelkalk between the Bunter and Keuper of that country; but the effect of this depression does not appear to have extended beyond the east of France, and was not felt in England, where, on the contrary, there may have been a partial elevation. All the north and centre of France seems to have been high land throughout the Triassic period, parts of it, according to MM. Cornet and Briart, rising into lofty peaks 16,000 to 20,000 feet above the sea-level of the time.

In Keuper times there seems to have been an elevation of the whole northern area, converting it into a region of great lakes which were probably more or less isolated from one another, and in which the thick beds of red sandstone, marl, and rock-salt were laid down. The ripple-marks, sun-cracks, and reptile-tracks so frequent on the surface of the Keuper standstones, show that the volume of the lake-waters was subject to variations, and that there were times when tracts of sand were exposed and dried in the sun, and on these the strange reptiles of the period have left their footmarks. It was also principally during such times of partial desiccation that the beds of rock-salt and gypsum were deposited by precipitation from the saline waters.

Confining our view now to the area of the British Islands, we find in early Triassic times three separate areas of deposition: one in the south, where the Devon and Dorset Trias was formed; one in the north-west, over the site of the western Dyas lake; and one in the north-east, which was probably a long and comparatively narrow tract bounded both on the east and west by ranges of mountains. The southern lake was separated from the northern water-system by an eastward prolongation of the Mendip Hills until the epoch of the Keuper beds, when this barrier was overflowed, and the southern basin became an arm of the great inland sea of the Keuper.

Let us first consider the conditions which prevailed in the southern area during Bunter times; we find it bounded on the west and south by continuous and probably mountainous land extending from Wales, through Devon and Cornwall, to France and Belgium, the shores of the lake running across from South Devon (Torquay) to Normandy, where there is a small area of Trias, though it is doubtful whether any of it is of Bunter age. The Bristol Channel was a fiord narrowing westward instead of eastward as now, and there were other similar inlets or fiords running westward into the Devonshire mountains. On the east and north this lake was bounded by a projecting mass of land which stretched from Belgium through the east of England and was united to Wales by an isthmus over the present counties of Worcester, Gloucester, and North

Somerset. The Mendip Hills were part of this isthmus, and its eastern extension is proved by the borings mentioned on p. 265.

The western coasts of this lake were steep and rocky mountainous tracts of Palæozoic rocks, probably coming close to its shores, just as the Maritime Alps border the shores of the Riviera. It seems, indeed, as if the conditions under which the lower breccias and pebbly sandstones of Devonshire were accumulated, must have been very similar to those which have long existed in the Riviera. Sir Charles Lyell describes some remarkable deposits near Nice;[1] there torrents from the Alps bring down vast quantities of detritus, fine in summer, coarse in winter, and this is poured into the Mediterranean, and deposited in slanting layers immediately outside the mouths of the torrents, the shore being so steep that depths of 2,000 and 3,000 feet are found within half a mile of the beach. An elevated delta of this kind can be studied in the valley of the Magnan (near Nice), where inclined beds of sand, marl, gravel, and conglomerate succeed one another in cliffs 200 to 600 feet high for a distance of nine miles; if their inclination were assumed to be a dip, this would give a thickness of many thousand feet, whereas their real thickness cannot be proved to be even 1,000.

Similar accumulations are probably frequent where the conditions are similar, and the aspect of the coarse sandstones of Teignmouth and Dawlish, with their angular fragments of local rocks, seem to be torrential deposits of this kind. The overlying marls may indicate submergence which carried the coast-line farther west, and so allowed a finer sediment to rest upon the coarse shore-beds.

The pebble-beds of Budleigh Salterton testify to the existence of strong currents, which appear to have set from the southward, for it has been shown that the quartzites are identical in character and fossil contents with certain quartzites of Ordovician age in Brittany,[2] viz., the Grés Armoricain (Llandeilo) and the Grés de May (Bala). There is little doubt, therefore, that these pebbles were

[1] "Students' Elements of Geology," fourth edition, 1885, p. 20.
[2] Davidson, "Geol. Mag.," Dec. 2, vol. vii. p. 337.

brought either from Brittany or from land between Brittany and Cornwall.

Whether the northern areas were at this time lake-basins or low-lying terrestrial surfaces on which subaerial deltas were accumulated is very uncertain. Professor Ramsay suggests a lacustrine origin for the whole of the British Trias, but Professor Bonney remarks[1] that "the number and size of the pebbles (in the Bunter) seem to point to the action of strong currents, such as would only occur in an open sea or in the delta of a large river. The average Staffordshire pebbles would require a current of about three miles an hour to sweep them along. Larger pebbles, up to six or eight inches in diameter, are by no means infrequent." That the currents were marine is very improbable, therefore, Professor Bonney argues, we are compelled to regard the pebble-beds as river-deposits, and the Bunter generally as a delta formation.

Where the quartzite pebbles came from is another puzzling question. A Scotch origin has been suggested for them, and Professor Bonney finds that many of them are identical in microscopic characters with the quartzite of Ross-shire, while others are like the harder parts of the Torridon sandstone. The pebbles of these two varieties may have been originally embedded in the Old Red Sandstone conglomerates, which are known to occur as far south as Arran and Ayrshire, and these being exposed to erosion in Triassic times, would yield their pebbles to the younger formation. Pebbles of felstone, resembling Scotch rocks of that class, are also by no means rare. There are, however, pebbles of a third kind of quartzite in the Bunter beds of Staffordshire, which do not appear to have travelled so far, for these contain fossils of Llandovery species, and have probably been derived from the quartzite of the Lickey Hills in Staffordshire, and perhaps from other masses of the same age (now concealed or destroyed) along the southern border of the Triassic area.

Another fact to be explained is the diminution of the pebbles, both in size and number, as the beds are traced northward in the direction of the source of supply. If the

[1] "Geol. Mag.," Dec. 2, vol. vii. p. 407.

pebble-beds were local deposits, occurring principally at the northern ends of the two Triassic tracts, there would be little difficulty in accounting for them; but they are, on the contrary, spread out over a large area at the southern end of these tracts, and appear to be nearly co-extensive with the sandstones which overlie them; they attain their maximum thickness in Cheshire, but diminish much more rapidly northward than they do southward.

If we adopt the lake theory, we must suppose two long, narrow, and shallow sheets of water, each receiving the current of a rapid river at its northern end. To account for the character and limited extent of the Lower Bunter Sandstone, we must conclude that the rivers were at first only of sufficient volume and velocity to carry sand into the lakes, and that their sandy deltas gradually filled up the spaces which were then covered by water. The wider extension of the Pebble Beds may indicate a rise in the level of the lake-waters due to an increased winter rainfall, an increase which may have been caused by a general elevation of the country. The rivers then became equal to transporting pebbles over the same areas, and a pebbly delta was superimposed upon the sandy one, gradually extending beyond the tracts covered by the lower sandstones, and round the southern termination of the Pennine range; the eastern and western waters then communicating over the tract which is now the valley of the Trent. The upper sandstones, if deposited in water, would indicate a decrease in the velocity of the incurrent streams, and a return to the former conditions, but with a larger lacustrine area for the reception of the sandy deposits.

This view of the manner in which the Bunter series was laid down is not altogether satisfactory. Professor Bonney tells me he has always felt it difficult to explain the great length of these Triassic tracts on the "filled-lake" theory, and to account for the entire absence of mud or shale. He thinks that the idea of subaerial river deltas, such as are found in some parts of India and Abyssinia, offers a simpler explanation of some of the facts. On this theory, the tracts now covered by the Bunter were flat lands on to which the rivers from the north swept the detritus which they carried, at first dropping the pebbles in the mountain valleys, and

only carrying sand on to the plains. When the period of increased rainfall came on they would carry pebbles, and at the time of maximum rainfall the detritus accumulated in the upper valleys might be swept out, and spread over the lowlands. Depression and decreasing rainfall would bring back the former conditions, and a recurrence of sandy deposits, the final arrangement of which was probably due to the action of wind, for Mr. J. A. Phillips has shown that some of the sandstones are composed of worn and rounded grains, like those of wind-drifted sands. We may, therefore, picture the surrounding country as a barren and rocky region, dry and wind-swept in the summer, with scanty vegetation and little animal life.

It is quite possible that the tracts in question were shallow lakes in the rainy season and dry surfaces in the summer, the rivers only filling their channels in the time of heavy rains, as is the case with many watercourses in Egypt and Abyssinia at the present day. In those countries immense quantities of *débris* are swept out of the hill valleys by sudden floods, and spread far and wide over the plains below, which in the dry season form arid tracts of sandy and pebbly desert. It is probably to such regions that we must look for a type of the conditions which prevailed during the earlier part of the Triassic period in Britain.

Whether any channel of connection existed between the midland tract and the southern lake we cannot say at present, but it is possible that the overflow waters may have cut a gorge through the intervening barrier of Palæozoic rocks, and that the buried channel may yet be discovered beneath the Keuper and Lias east of the Mendips.

The general depression which ushered in the Keuper series submerged the isthmus which separated the two British areas of deposition and widely extended these areas, so that the whole became part of an immense lake or inland sea. The Palæozoic ridge below Essex and Herts was still a promontory jutting out from Belgium, but the sea occupied the whole centre of England, and was prolonged into two gulfs or arms, a north-western stretching as far as the north of Ireland, and a southern covering the south of England, and the area of the English Channel, but not extending far into France.

The general resemblances between the Triassic beds of Scotland and the Keuper of England lead one to conclude that the former belong to the later part of the Triassic period; but however this may be, the occurrence of marls and limestones, and the existence of bivalve shells in the sandstones, make it certain that the Scotch strata were accumulated in lakes. Whether these lakes were connected with the larger one which lay over England it is impossible to say, but the balance of probability is, perhaps, against such a supposition, and in favour of their forming two distinct areas of deposition, one on the eastern and the other on the western side of the Scottish Highlands. The coarse breccias which form the basement beds of the series in Western Scotland were doubtless accumulated in the same manner as those of Bunter age in Devon.

## CHAPTER IX.

### THE JURASSIC SYSTEM.

FROM the prevalence of Oolitic limestones in the central part of this system in England, it was formerly (by Conybeare and Phillips) termed the Oolitic series; subsequently the Lias was described as separate from the Oolites, which were divided into Upper, Middle, and Lower groups, each being regarded as equivalent in value to the Lias, and the whole (including both Lias and Oolites) was eventually termed the *Jurassic System*, that name being used on the Continent for the equivalent rocks which form the Jura mountains between France and Switzerland.

The division into Lias and Oolites is, however, an awkward and inconvenient one, and a much more simple arrangement has recently been proposed, namely, to divide the whole Jurassic system into three great series—a Lower, Middle, and Upper; the Lower being the Lias, the Middle being what was formerly called the Lower Oolite, and the Upper including the groups formerly called the Middle and Upper Oolites, but which are really one indivisible series.

This arrangement will be adopted in the following pages, and the minor groups which constitute the three great divisions of the Jurassic system are given below:—

| | | Maximum thickness. |
|---|---|---|
| Upper Jurassic Series. | Portland Beds | 170 |
| | Kimeridge Clay | 600 |
| | Coral Rag or Corallian | 200 |
| | Oxford Clay | 600 |
| Middle Jurassic Series. | Great Oolite group | 450 |
| | Inferior Oolite group | 400 |

| | | Maximum thickness. |
|---|---|---|
| Lower Jurassic Series. | Upper Lias . . . . | 300 |
| | Middle Lias . . . . | 500 |
| | Lower Lias . . . . | 500 |
| Rhætic or Penarth Beds. . . . | | 40 |

The Rhætic or Penarth Beds (sometimes called the zone of *Avicula contorta*) are here included in the Jurassic system, because they are more conveniently described with the Lias, and because in Britain and Germany they are more closely connected with the Lias than with the underlying Keuper marls, from which they are usually separated by a sharp line of demarcation. In the Rhætic Alps, however, this thin zone swells out into a thick deep-water formation, which forms a series intermediate between the Trias and Lias, with fossils which link it more closely to the former than the latter.

The line of demarcation at the top of the Keuper marl in Britain is doubtless due to the invasion of the great Triassic lakes by the waters of the Rhætic sea, and to the consequent superposition of marine upon lacustrine beds; where there is a complete series of marine Trias and Lias the Rhætic beds show a gradual passage between the two systems. The reader will, therefore, remember that it is only for the sake of convenience that the Penarth Beds are dealt with in this chapter.

The Lias is essentially a clay formation, with occasional bands of limestone and ironstone of variable thickness.

The Middle Jurassic series consists mainly of limestones, with only subordinate bands of clay.

The Upper Jurassic, again, is an argillaceous series, the limestones being discontinuous and sometimes absent or replaced by clays.

The most persistent formations are the three great clays: the Lower Lias, the Oxford, and the Kimeridge Clay. These range all across England, and form broad tracts of low-lying land; while the intermediate limestones, where they are well developed, form long ridges, with escarpments facing the west or north-west, in consequence of the prevalent easterly dip (see figs. 64 and 65).

It was long ago remarked by Dr. Buckland that a line

drawn through England from the mouth of the Tees to the coast of Dorset, and corresponding with the base-line of the Jurassic system, would divide the country into two totally dissimilar parts, contrasting strongly with each other, both in their physical and economical aspects. The country to the north-west of this line is chiefly composed of Palæozoic rocks, which often rise into barren mountainous tracts, but which in many places contain valuable minerals, such as coal, iron, lead, copper, and tin. The country to the south-east of the line is entirely Neozoic ground, the greater part of which has a fertile soil, but little subterranean wealth, and few parts of which rise to an elevation of 900 feet. The first-mentioned part of the country is largely inhabited by a mining and manufacturing population, while the inhabitants of the south-eastern districts are chiefly employed in agricultural pursuits.

The rate of change in the organic world and the differentiation of species appears to have become much more rapid in Jurassic times than it had previously been, so that any given group of species has a much less vertical range, and consequently a much smaller set of strata requires separate description. It will, therefore, be convenient to consider each of the three major divisions of the system separately, the Rhætic being taken with the Lias.

## § A. Rhætic and Lias.

**Geographical Range.**—The Rhætic Beds succeed the Keuper marls[1] near Axmouth on the Dorset coast, but inland their outcrop is concealed for some distance by the overlap of the Cretaceous rocks which form the Blackdown Hills. They emerge again to the north-west of Ilminster, and run through Somerset to Wells and Shepton Mallet on the south side of the Mendip Hills. They fringe these hills, but are in places overlapped by the lowest beds of the Lias;

[1] The uppermost beds of the Keuper marl are of a greenish grey colour, and were formerly grouped with the Rhætic, but the tint is probably due to the reduction of the peroxide of iron to the protoxide by the action of the water which percolates through the pyritous shales of the Rhætic, and becomes impregnated with sulphuretted hydrogen.

thence they pass through Gloucester to Aust Passage and Westbury on Severn.

Outlying tracts of the Rhætic Beds are found on both sides of the Bristol Channel, near Watchet in Somerset, and at Penarth in Glamorgan; but as they pass westward from the latter locality they are overlapped by the Lias.

From the Severn the Rhætics are traceable as a narrow but continuous band all across England, between the broad tracts occupied by the Trias and Lias, running through the counties of Worcester, Warwick, Leicester, Nottingham, and Lincoln, to the valley of the Trent north of Gainsborough.

The Rhætic beds are probably continuous from the Humber northwards, but have not been seen south of Howsham in the valley of the Derwent; and in the North Riding they are nearly everywhere concealed by Pleistocene deposits, but are seen occasionally, as at Northallerton, and thence to Redcar.

The Lias occupies the coast of Dorset from Axmouth nearly as far as Bridport, and its inland outcrop forms a broad tract of country stretching across England to the east and south-east of the line indicated for the Rhætic beds.

Outlying tracts of Rhætic and Lias occur in Staffordshire, at Needwood Forest, and north of Abbots Bromley; in Shropshire, between Wem and Audlem, and in Cumberland, near Carlisle; proving that the formation originally extended far to the north-west of its main line of outcrop. There is little doubt, indeed, that the Lias was once coextensive with the Trias, but there is no indication that it ever extended far beyond the limits of the Keuper marls.

In Scotland remnants of both Rhætic and Lias occur above the Trias on the east coast of Sutherland, and the Lias is also found on the west coast, but the Rhætic is not there represented.

In Ireland they crop out in certain places from beneath the Cretaceous rocks of Antrim, but only Rhætic and Lower Lias are found, the higher beds having been removed before the deposition of the Cretaceous rocks.

With regard to the eastward subterranean extension of the Lias in England, it is known that its upper beds, as

they pass beneath the higher members of the Jurassic system, thin very rapidly. Thus in a boring at Burford, in Oxfordshire, the Middle and Upper Lias are together less than 30 feet thick; the Lower Lias is there about 620 feet thick, and the Rhætic is 10 or 12 feet; but between that place and Richmond these have both disappeared, allowing rocks of the Middle Jurassic series to rest directly on rocks which are supposed to be Trias. It would appear, therefore, that between Richmond and the Malvern Hills the width of ground now occupied by the Lias is less than 100 miles: it may originally have extended somewhat further eastward, but is not likely to have covered the tract of Palæozoic rocks which underlies the eastern counties (see fig. 53, p. 267).

## Life of the Period.

**Marine Fauna.**—The Rhætic zone of *Avicula contorta* is the earliest marine bed of Mesozoic age in Britain, because throughout Triassic times our islands formed part of a large continent which occupied the northern part of Europe, and it was not until the epoch of this zone that the southern sea spread over the inland lakes of the northern area. We are thus suddenly presented with an assemblage of fossils which are utterly different from those of the Carboniferous and Dyassic periods, and for the ancestors of which we must search the marine Trias of the Alps. A still larger number of genera and species make their appearance in the Lias, and the following is a list of the chief genera which are not known in Britain before the date of the Rhætic beds, but occur either in them or the Lias:—

*Actinozoa.*—Astrocœnia, Isastrea, Montlivaltia, Thecosmilia, Thamnastrea.

*Echinodermata.*—Aspidura, Ophioderma, Acrosalenia, Cidaris, Hemipedina, Pseudodiadema, Extracrinus, Pentacrinus, Astropecten.

*Crustacea.*—Eryon, Eryma, Glyphæa.

*Brachiopoda.*—Waldheimia, Thecidium, Terebratella.

*Lamellibranchiata.*—Arca, Astarte, Cardium, Cardinia, Ceromya, Goniomya, Gresslya, Gryphæa, Hinnites, Lucina?

Myoconcha, Opis, Ostrea, Perna, Placunopsis, Plicatula, Pholadomya, Pleuromya, Thracia, Tancredia, Trigonia.

*Gasteropoda.*—Alaria, Amberleya, Actæonina, Cerithium, Chemnitzia, Nerinæa, Neritopsis, Purpuroidea, Solarium, Tornatella, Trochus? Tectaria (Eucyclus), Trochotoma.

*Cephalopoda.*—Ammonites, Belemnites, Beloteuthis.

*Fish.*—Dapedius, Eugnathus, Lepidotus.

*Reptiles.* — Ichthyosaurus, Plesiosaurus, Teleosaurus, Pterodactylus, Megalosaurus.

The species found in the English Rhætics number 125; those known from the Lias number 1800. The following are the most characteristic species of each group:—

## Fossils of the Rhætic.

*Lamellibranchiata.*—Avicula contorta, Cardium Rhæticum, Pecten Valoniensis, Schizodus elongatus, Pullastra arenicola.

*Fish.*—Acrodus acutus, Ceratodus altus, Hybodus minor, Nemacanthus monilifer, Saurichthys apicalis.

*Reptiles.*—Ichthyosaurus and Plesiosaurus first occur.

*Mammals.*—Microlestes antiquus (a small Marsupial).

## Fossils of the Lower Lias.

*Actinozoa.*—Montlivaltia Haimei, Isastrea Murchisoni.

*Echinodermata.*—Hemipedina Bechei, Cidaris Edwardsii, Extracrinus Briareus, Pentacrinus basaltiforme.

*Brachiopoda.*—Spiriferina Walcottii, Rhyn. variabilis.

*Lamellibranchiata.*—Avicula cygnipes, Cardinia Listeri, Ostrea liassica, Lima gigantea, Gryphæa incurva, Hippopodium ponderosum.

*Gasteropoda.*—Pleurotomaria anglica, Tectaria (Eucyclus) elegans, Cerithium gratum.

*Cephalopoda.*—Ammonites planorbis, Am. angulatus, Am. Bucklandi, Am. Turneri, Am. obtusus, Am. oxynotus, Am. raricostatus, Belemnites acutus, Bel. clavatus.

*Fish.*—Dapedius politus, Hybodus reticulatus.

*Reptiles.*—Ichthyosaurus communis, I. intermedius, Plesiosaurus dolichodeirus, P. Hawkinsii.

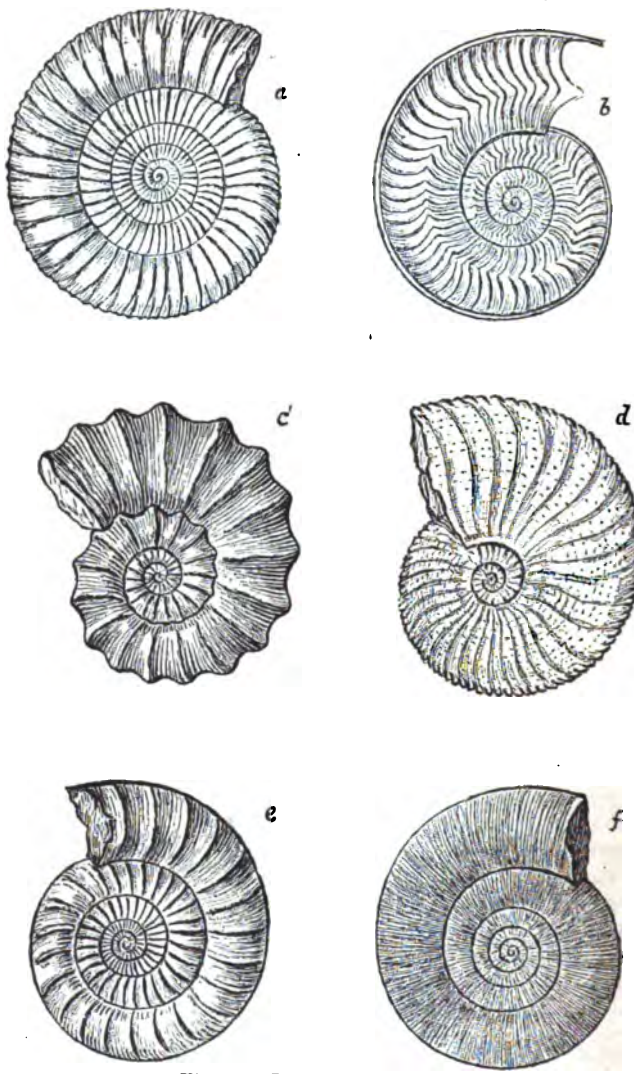



Fig. 59. Liassic Ammonites.

*a.* Ammonites communis ($\frac{1}{2}$).
*b.* ,, serpentinus ($\frac{1}{2}$).
*c.* ,, capricornus ($\frac{1}{3}$).
*d.* Ammonites margaritatus ($\frac{1}{3}$).
*e.* ,, Bucklandi ($\frac{1}{6}$).
*f.* ,, planorbis ($\frac{1}{2}$).

## Fossils of the Middle Lias.

*Actinozoa.*—(None common.)

*Echinodermata.*—Tropidaster pectinatus, Ophioderma Egertoni, O. Milleri.

*Brachiopoda.*—Terebratula punctata, Waldheimia resupinata, Rhynchonella tetrahedra, R. acuta.

*Lamellibranchiata.*—Plicatula spinosa, Crenatula ventricosa, Modiola scalprum, Avicula inæquivalvis, Cardium truncatum, Pecten æquivalvis.

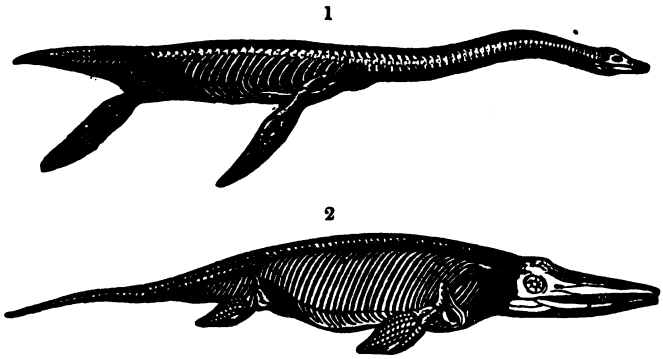



Fig. 60. Liassic Reptiles.

1. Skeleton and restored outline of Plesiosaurus dolichodeirus ($\frac{1}{60}$).
2. Skeleton and restored outline of Ichthyosaurus communis ($\frac{1}{60}$).

*Gasteropoda.*—Trochus imbricatus, Cryptænia expansa.

*Cephalopoda.*—Ammonites Jamesoni, Am. capricornus, Am. spinatus, Am. margaritatus, Belemnites elongatus, B. paxillosus.

*Fish and Reptiles* are rare.

## Fossils of the Upper Lias.

*Actinozoa.*—(None common.)

*Echinodermata.*—Acrosalenia crinifera (minuta).

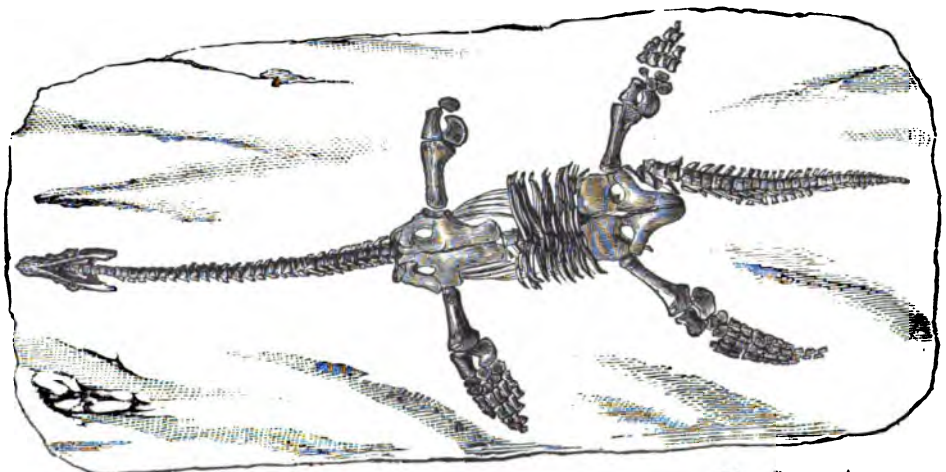


Fig. 61. Plesiosaurus Hawkinsii ($\frac{1}{18}$), ventral aspect, from Lower Lias, Somerset.

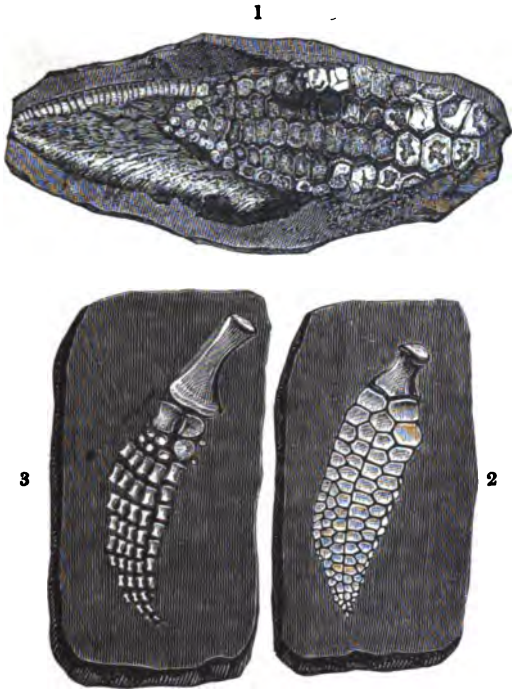



Fig. 62. Limbs of Ichthyosaurus and Plesiosaurus.

1. Hind limb of Ichthyosaurus, with the impression of its skin.
2. Fore limb of Ichthyosaurus ($\frac{1}{8}$), Lower Lias.
3. Fore limb of Plesiosaurus ($\frac{1}{8}$), Lower Lias.

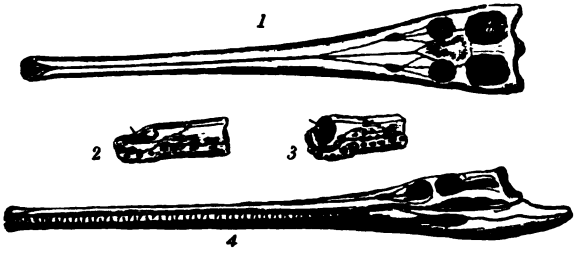



Fig. 63. Skull of Teleosaurus Chapmanni ($\frac{1}{8}$), Whitby.

1. Upper view.
4. Side view.
3. Side view of snout.
2. Snout of Steneosaurus.

*Brachiopoda.*—Discina reflexa, Leptæna Moorei.

*Lamellibranchiata.*—Inoceramus dubius, Posidonomya Bronnii, Leda ovum, Myacites donaciforme.

*Gasteropoda.*—(None very common.)

*Cephalopoda.*—Am. communis, Am. serpentinus, Am. bifrons, Am. annulatus, Belemnites irregularis.

*Fish.*—Lepidotus semi-serratus, Gyrosteus mirabilis.

*Reptiles.* — Ichthyosaurus acutirostris, Plesiosaurus longirostris, Teleosaurus Chapmanni.

## Zones of the Lias.

The three divisions of the Lias are capable of being subdivided into zones, each of which is characterized by a certain number of species, and certain species of Ammonites have been chosen as indices of these zonal faunas. Even still smaller belts or subzones are often recognized, but are not so persistent as the larger zones, which are given below:—

| | | | | |
|---|---|---|---|---|
| Upper Lias. | 4. | Zone of | Am. jurensis. | |
| | 3. | „ | Am. bifrons and Am. communis. | |
| | 2. | „ | Am. serpentinus. | |
| | 1. | „ | Am. annulatus. | |
| Mid. Lias. | 4. | „ | Am. spinatus. | |
| | 3. | „ | Am. margaritatus. | |
| | 2. | „ | Am. capricornus and Am. Henleyi. | |
| | 1. | „ | Am. Jamesoni | A. ibex.<br>A. Jamesoni.<br>A. armatus. (Sub-zones.) |
| Lower Lias. | 5. | „ | Am. oxynotus | A. raricostatus.<br>A. oxynotus.<br>A. obtusus. (Sub-zones.) |
| | 4. | „ | Am. Turneri and Am. semicostatus. | |
| | 3. | „ | Am. Bucklandi. | |
| | 2. | „ | Am. angulatus. | |
| | 1. | „ | Am. planorbis. | |

The Lower Lias, both of England and the Continent, falls naturally into three stages, viz.:—

Oxynotian or Belemnite Beds = Zone 5.
Arietian or Gryphitian = Zones 3 and 4.
Hettangian or Limestone Series = Zones 1 and 2.

The first is characterized by the prevalence of the *oxynotus* type of Ammonites; the second by the abundance of Gryphæa and Ammonites of the *Arietites* group; the third is named from a district in Germany.

**Terrestrial and Freshwater Fauna.**—Plant remains occur but rarely in the Lias, but some Cycads and Conifers have been found. Certain thin limestones at the base of the Lower Lias have yielded remains of small plants (*Naiadites*) and insects of many genera; similar remains occur also at a particular horizon in the Upper Lias.

In 1866 Mr. C. Moore [1] obtained a most remarkable set of land and freshwater Mollusca mixed with marine species of Lower Liassic age from material filling large fissures in the Carboniferous Limestone of the Mendip Hills. They comprised snails of the genera *Helix*, *Proserpina*, and *Vertigo*, together with species belonging to the freshwater genera *Melania*, *Amberleya*, *Planorbis*, and *Valvata*. *Melania* is also found in the Lower Lias of Glamorgan, and some of the species referred to *Trochus* and *Cerithium* by Mr. Moore resemble this genus. The insects which have been found include representatives of several orders,—Beetles (Coleoptera), May-flies (Neuroptera), and Grasshoppers (Orthoptera); all of them are closely allied to existing forms, and are such as would inhabit temperate climes, being probably brought down by flooded streams draining the high lands which bordered the Liassic sea. On this point Sir A. Ramsay has some interesting remarks. During the Triassic and Liassic periods, he says, it is not improbable to suppose that the mountains of Wales were at least double their present height, and were, therefore, 5,000 to 6,000 feet high, so that if a tropical or warm temperate fauna existed along the coast, a cold temperate land-fauna might exist among the hills. The Rev. P. B. Brodie has in fact remarked that the insects found in the Secondary rocks are (with certain exceptions) of a minute size, such as would

[1] "Quart. Journ. Geol. Soc.," vol. xxiii. p. 494.

inhabit a cold or temperate climate. Now Professor Edward Forbes, while dredging along the coast of Lycia (Asia Minor), "observed that during the rainy season, the surface of the water was often partially covered with quantities of dead insects, washed into the sea from the neighbouring land. By far the greater number of these insects were not derived from the hot low-coast territories, but were borne to the sea from the more distant and lofty mountain lands (7,000 to 10,000 feet high), by sudden floods which are then of frequent occurrence." They also, in accordance with the elevated regions from whence they came, bore the characters of temperate and cold climates; and Sir A. Ramsay thinks it probable "that the insect remains described by Mr. Brodie were washed from the mountain country we have described into the surrounding seas, and there entombed amid creatures of a tropical character."[1]

## Stratigraphy.

### 1. *Dorset and Somerset.*

**Rhætic Beds.**—Good sections of these beds are found near Lyme Regis in Dorset, near Watchet in Somerset, and in the railway cutting near Queen Camel. They consist of two members—(1) the Black or "Paper shales, (2) the White Lias. The black shales generally contain one or two sandy layers near the base which are crowded with the teeth, scales, bones, and coprolites of fish and reptiles, and hence are known as "bone beds." These contain *Avicula contorta, Pecten valoniensis*, and other fossils. The upper member consists of marly limestone white or cream-coloured, the topmost bed being a hard, compact, and smooth-grained limestone known as "tun-bed."

At certain places on the Mendip Hills deposits and conglomerates occur, marking the shore of the Rhætic sea; and some fissures in the Carboniferous limestone at Holwell, near Frome, have yielded immense number of Rhætic fossils (teeth and bones of reptiles, and *Microlestes*).

[1] Ramsay, "Denudation of South Wales," Geol. Survey, vol. i. p. 325.

Near Queen Camel the thickness of the lower shales and sandstones is 49 feet, and that of the White Lias is 21 feet, making a total of 70 feet. At Camerton, north of the Mendips, there is White Lias (8 feet) and shales (15 feet).

**Lower Lias.**—Most of the zones of the Lower Lias are discernible along the coast of Dorset, near Lyme Regis. The *planorbis* zone, some 40 feet thick, consists of alternating limestones and shales in thin beds, with *Am. planorbis*, *Ostrea liassica*, and *Cidaris Edwardsii*. The *angulatus* beds are dark shales with seven beds of impure limestone (total 13 feet). The *Bucklandi* zone is 170 feet thick, and consists of shales with concretionary limestones, all very fossiliferous, the bivalves *Gryphæa incurva* and *Lima gigantea* being very common; at its summit is a bed of impure limestone, 3 feet thick, containing *Am. Turneri*, *Am. semicostatus*, and bones of *Ichthyosaurus*; this bed is known as the "broad ledge," or "table-bed." Above it are dark marls (80-100 feet) with septaria containing *Am. obtusus* and *Am. stellaris*. Above these are the *oxynotus* shales or "Belemnite beds" (? 100 feet), with *Am. oxynotus*, *A. raricostatus*, *Belemnites acutus*, and *Cardinia Listeri*, &c.

In Dorset and South Somerset the Lower Lias is supposed to be 500 to 600 feet thick, and the zone of *Am. planorbis* is well exposed near Street and Queen Camel, but it thins rapidly toward the Mendip Hills, and at Camerton on the north side it is reduced to a mere band, only 16 feet thick, lying between the Rhætic and the reduced equivalent of the Middle Lias.

**Middle Lias.**—In Dorset these beds are over 300 feet thick, but no definite representative of the *Jamesoni* zone occurs. The lowest beds are clays (100 feet) containing *Am. Henleyi*, *Am. Davœi*, and *Am. laticosta*, and the starfish bed near the summit contains *Ophioderma Egertoni*. Next come micaceous marls with *Am. margaritatus* (180 feet); and above are micaceous sands and marls with *Am. spinatus* (80 feet), with a thin seam of ferruginous marlstone.

The Middle Lias varies much in thickness, but is persistent through Dorset and Somerset, thinning near the Mendips and represented at Camerton by a mere seam of clay and marlstone only two feet thick.[1]

[1] C. Moore, "Quart. Journ. Geol. Soc.," vol. xxiii. p. 471.

**Upper Lias.**—In Dorset this division consists of two members: (1) Clays representing the zones of *A. annulatus*, *A. serpentinus*, and *A. bifrons*, 70 feet; (2) Sands forming the zone of *A. jurensis*, about 150 feet; these are the Midford Sands of Professor Phillips, who regarded them as passage-beds between the Lias and Inferior Oolite, but they are capped by the well-marked "Cephalopoda Bed" (or zone of *Am. opalinus*), aud are best placed with the Lias.

In Somerset, near Ilminster, the clays are reduced to a thickness of 8 or 10 feet, but are full of fossils, one thin bed of marl alone yielding 150 species to Mr. Moore; this is known as the "Leptæna marl," from the abundance of *Leptæna Moorei* and *L. Bouchardi*. Above it is a nodular argillaceous limestone with remains of saurians, fish, and insects. The overlying sands are well exposed near Yeovil and Sherborne, where their thickness is 140 feet; north of the Mendips they are much thinner, being only 40 feet at Bath.

### 2. *Gloucester, Glamorgan, and the Midlands.*

**Rhætic Beds.**—These are well exposed in cliff sections at several points along the estuary of the Severn; namely, Penarth, Aust Passage, and Westbury; also at Wilmcote near Stratford-on-Avon. Where fully developed both the Black Shales and the White Lias are found, but the latter thins north-eastward, as shown below:—

| | Penarth. | Westbury. | Tewkesbury. | Wilmcote. |
|---|---|---|---|---|
| White Lias | 18 | 10 | 6 | 3 feet. |
| Black Shales | 24 | 24 | 24 | 26 feet. |

The basal beds are sandy shales, with one or two bone-beds; these rest on the grey marls which are sometimes included in the Rhætic. Above are black shales with *Cardium rhæticum*, *Pecten*, &c.

Near Penarth the White Lias is wholly calcareous, but near Bristol it consists of grey shales with thin limestones, containing *Estheria minuta* and plant remains (*Naiadites*, &c.), the lowest bed being the Cotham stone, or "landscape marble;" but these beds thin out to the north-east.

In Glamorganshire, between Pyle and Bridgend, the whole group is represented by sands and sandstones, with *Pullastra arenicola*, which lie in hollows of the Carboniferous limestone, and are overlapped by the Lias limestones.

**Lower Lias.**—The lowest beds of the Lias zones of *Am. planorbis* and *Am. angulatus* are well exposed along the south coast of Glamorgan, in a cutting at Saltford near Bath, and at Wilmcote in Warwickshire. In their normal form they consist of thin limestones and shales in alternating layers, with two persistent layers of limestone at the base, the lowest characterized by *Monotis decussata* and insect remains, the higher by *Ostrea liassica*. In their westward extension, however, they exhibit a remarkable lithological change; at Sutton and Brocastle near Bridgend (Glamorgan), they consist of massive limestones, conglomeratic at the base, resting either on the Rhætic sands, or on the Carboniferous limestone. Corals of the genera *Astrocœnia*, *Montlivaltia*, and *Thecosmilia* are predominant in the basement beds, together with *Monotis decussata* and *Ostrea liassica*; the higher beds contain *Ammonites angulatus* and *Littorina clathrata*.[1]

These lower zones are everywhere covered by shales and limestone bands, containing *Am. Bucklandi*, *Am. Conybeari*, *Gryphæa incurva*, and *Belemnites acutus*. The higher zones of *Am. Turneri* and *Am. oxynotus* are also well developed, and can be seen at Bredon and Cleeve, near Cheltenham, the subzone of *Am. raricostatus* occurring at the top.

**Middle Lias.**—In the Cotteswold Hills this division has an average thickness of 150 feet, consisting of clays at the base, with *Am. Jamesoni*, *Am. ibex*, and *Am. Henleyi*, sands and sandy clays, with *Am. margaritatus* capped by the Marlstone rock-bed, a ferruginous limestone 12 to 20 feet thick. In Warwick, Oxford, and Northampton, the series is reduced to the rock-bed, with a variable thickness of sands and clays below, these being only 24 feet thick at Burford, and only 10 near Ascott.

**Upper Lias.**—This portion, which is so thin near Bath,

[1] See "Quart. Journ. Geol. Soc.," vol. xxiii. pp. 12, 199, 305, papers by Bristow, Duncan, and Tate.

thickens out rapidly northward, and is 300 feet thick at Cleeve Cloud near Cheltenham. Fine sections occur on the Cotteswolds (Dumbleton, Bredon, &c.), the *serpentinus* zone having a *Leptæna* marl and insect limestones as at Ilminster; the upper clays belong to the zone of *Am. bifrons*, and the Midford sands above are from 30 to 40 feet thick.

North-eastward the Upper Lias rapidly thins again to 100 feet, preserving this thickness along its outcrop in Warwick and Northampton, but when traced along the valleys which lead eastward it becomes still more attenuated; thus at Stow and Sarsden there is only 40 feet, at Burford only 20 feet, and at Fawler only 6 feet of clay, the Midford sands having entirely thinned out, as well as the upper beds of clay, that which remains containing *Am. annulatus*, *A. serpentinus*, and *A. communis*.

### 3. *Leicester and Lincoln.*

In these counties we find the following zones:—

| | |
|---|---|
| Upper Lias. | Clays with *Am. bifrons* and *Leda ovum*. |
| | „ with *Am. communis*. |
| | „ with *Am. serpentinus*. |
| | Shales with fish and insect limestones. |
| Middle Lias. | Marlstone rock-bed (*Am. spinatus*). |
| | Blue micaceous clays with septaria and bands of sandy ironstone (*Am. margaritatus*). |
| | Blue clays with septaria (*Am. capricornus*). |
| | Blue clays with thin limestones and septaria (*Am. ibex* and *Jamesoni*). |
| | Sandy clays and sands, occasionally indurated into a stone (*Am. armatus*). |
| Lower Lias. | Blue clays with small septaria (*Am. oxynotus*). |
| | Ferruginous limestones with *Am. semicostatus*. |
| | Blue clays and grey limestones (*Am. Bucklandi*). |
| | Dark blue pyritous clays (*Am. angulatus*). |
| | Limestone and shales (*Am. planorbis*). |
| Rhætic. | White Lias, grey shaly marls with yellowish nodular limestones. |
| | Black pyritous shales with *Avicula contorta* and bone beds. |

**The Rhætic Beds** are similar to those of the southern counties; the *Avicula contorta* zone is from 10 to 18 feet

Fig. 64. Section through the Jurassic Series near Lincoln.

9. Oxford Clay.
8. Cornbrash.
7. Great Oolite Clay.
6. Great Oolite Limestone.
5. Upper Estuarine Clays.
4. Lincolnshire Limestone.
3. Upper Lias Clay.
2. Middle Lias Clay.
1. Lower Lias Clay.

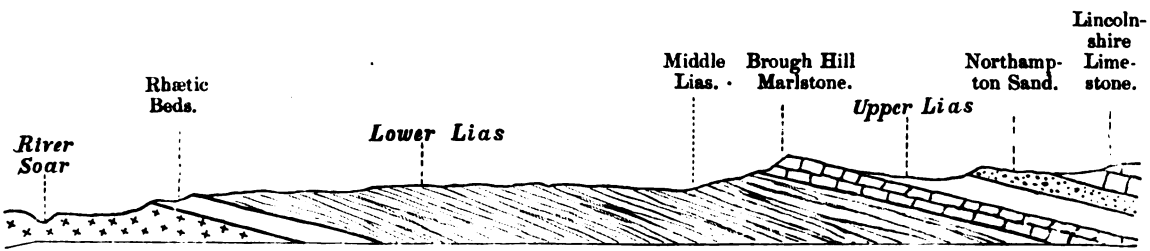



Fig. 65. General section through East Leicestershire (W. J. Harrison).
Distance about 20 miles.

thick, and the White Lias from 5 to 15. Sections may be seen at Leicester, and in several railway cuttings on the borders of Lincoln and Nottingham.

**Lower Lias.**—The zones of *Am. planorbis*, *Am. angulatus*, and *Am. Bucklandi* present the same features as elsewhere, and have a combined thickness of about 200 feet. They are succeeded by several beds of hard ferruginous limestone with interbedded shales (the *Am. semicostatus* zone), which thicken northward till they are 27 feet thick at Scunthorpe and Frodingham, where they are worked for ironstone. The *obtusus* zone is thin or absent, but clays with *A. oxynotus* and *A. raricostatus* occur, and are about 90 feet thick.

**Middle Lias.**—This appears to attain its maximum dimensions in Leicestershire and South Lincolnshire, where it is no less than 500 feet thick, the zone of *Am. Jamesoni* alone measuring 300 feet near Grantham; but this thins northward till it disappears altogether, and in north-west Lincolnshire the total thickness of the Middle Lias is less than 80 feet, the beds there found being:[1]—

| | Feet. |
|---|---|
| Marlstone rock-bed (ironstone) . . | 8 |
| Clays with *Am. capricornus* . . . | 66 |
| Ironstone with *Am. armatus* . . . | 4 |

The uppermost member or Marlstone varies greatly in thickness, sometimes swelling out to 30 feet, and forming a bold escarpment (as near Holwell, Eastwell, and Belvoir, where it is now largely worked for ironstone), sometimes thinning to a mere band, and even disappearing altogether for a space, as near Lincoln (see fig. 64).

**The Upper Lias** is about 200 feet thick in Leicestershire, but steadily decreases northward, till it is only 60 feet; thus in North Lincolnshire the whole thickness of the Lias is reduced from 1,000 to a little over 400 feet.

### 4. *Yorkshire.*

The Lias in the south of Yorkshire, from Brough to Kirby Underdale and Howsham, is similar in all respects

[1] J. E. Cross, "Quart. Journ. Geol. Soc.," vol. xxxi. p. 115.

to that of North Lincoln; but as soon as the valley of the Derwent is crossed a change begins to be manifest, both the Middle and Upper Lias swelling out till they again attain a development equal to that of South Lincolnshire. From Howsham the outcrop curves round by Thirsk and Northallerton to the coast between Redcar and Whitby, which exhibits an excellent section of the whole formation, except the zones of *Am. planorbis* and *Avicula contorta* (Rhætic).

The Rhætics are known to occur near Northallerton and elsewhere, but no good sections have been described. The "*planorbis*" beds are visible near Market Weighton. The following is a *résumé* of the coast section.

| | |
|---|---|
| Upper. 280 feet. | Cement beds and alum shale, including zones of *Am. jurensis* and *Am. bifrons*. |
| | Shales with jet beds, *Ams. communis* and *serpentinus*. |
| | Grey shales with *Am. annulatus*. |
| Middle. 400 feet. | Ironstone (Cleveland main seam) and shales below, zone of *Am. spinatus*, 30-90 feet. |
| | Ironstone (lower seam) or Pecten bed, with beds of marly sandstone below, *Am. margaritatus* and *Pecten lævis*, 40-60 feet. |
| | Clays with *Am. capricornus*, 60-130 feet. |
| | Shaly micaceous clays with *Am. Jamesoni*, 220 feet. |
| Lower. 370 feet. | Clays with *Am. oxynotus* and *raricostatus*, 100 feet. |
| | Shales and limestones with *Am. Turneri* and *Am. semicostatus*, 66 feet. |
| | Shales with limestone nodules, zone of *Am. Bucklandi*, 112 feet. |
| | Shales and thin limestones, *Am. angulatus*, 50 feet. |
| | Zone of *Am. planorbis* below, but not accessible. |

### 5. *Ireland.*

Beds of Rhætic and Liassic age occur only in the extreme north-east of Ireland; they crop out at several places in Antrim between the Trias and the Cretaceous series, but are frequently overlapped by the latter, and are then concealed from view. The best sections are at Colin Glen near Belfast, White Head, Island Magee, Larne and Glenarm; but nowhere is the top of the Lower Lias exposed.

**The Rhætic Beds** are about 100 feet thick at Colin Glen; the lowest beds are micaceous shales and sandstones

with fish remains; the middle beds are black shales with *Avicula contorta* and other fossils; the upper beds are grey and brown shales with thin limestones, with whitish marl and black shales above, forming a passage into the Lower Lias.

**Lower Lias.**—Of this division the following zones are found in descending order:—

4. Clays with *Belemnites acutus*, possibly representing the zone of *Am. Turneri*.
3. Blue argillaceous limestones, zone of *Am. Bucklandi*.
2. Blue marly clays with dark limestones, zone of *Am. angulatus*.
1. Black shales with *Am. planorbis*.

At Portrush the Lias shales are indurated and converted into hornstone by contact with igneous rock.

### 6. *West of Scotland.*

The Secondary rocks of the Inner Hebrides, like those of Ireland, owe their preservation to the enormous flows of lava which were poured out upon them in Tertiary times, and they now appear only in cliff sections or in valleys where the superincumbent lavas have been removed by subsequent erosion.

The existence of Liassic deposits at certain places on the west coast, and in the islands of Mull, Skye, and Raasay, has been known for a long time; but the most complete account of them is to be found in Professor Judd's masterly paper on the "Secondary Rocks of Scotland."[1] Nearly every zone of the Lias is represented, and the total thickness of the formation is not less than 1,200 feet.

**Lower Lias.**—The very base of this is never clearly seen, so that it is uncertain whether the Rhætics occur below; but Professor Judd believes them to be absent. The lowest beds of the Lias greatly resemble those of the same age in South Wales; they consist of very hard bluish-grey lime-

[1] "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 660; see also Bryce and Tate in "Q. J. G. S.," vol. xxix. p. 317.

stones, alternating with calcareous grits and conglomeratic sandstones. The commonest fossil is *Ostrea irregularis* (a variety of *O. liassica*), but corals *Thecosmilia Martini* and *Isastrea Murchisoni* also occur, together with *Cardinia concinna* and spines of *Acrosalenia*. *Ammonites* are not found, but the beds may be regarded as equivalent to the zones of *Am. planorbis* and *Am. angulatus*; their thickness is about 200 feet, and they are well seen at Applecross and on the opposite coast of Raasay.

The succeeding zone of *Am. Bucklandi* is well developed, and consists of shelly limestones and shales crowded with fossils of the same species which are common in England; its thickness is 250 feet. Above are dark micaceous shales containing *Am. semicostatus*, *Am. Brookii*, and *Belemnites acutus*, 150 feet. The separate existence of the *Am. oxynotus* zone is not determined, the fossils of this zone only occurring at Tobermory in Mull, where they are mingled with others that belong to higher horizons.

**Middle Lias.**—This is divisible into two well-marked members,—a lower consisting of sandy and micaceous shales, called the Pabba shales by Professor Judd, and an upper formed of sandstones, generally calcareous, to which the name of Scalpa beds is given. The Pabba shales have some beds at the base in which *Am. armatus* occurs, but the greater portion of the group represents the zones of *Am. Jamesoni* and *Am. capricornus*; they contain *Am. Jamesoni*, *Am. brevispina*, *Am. Davœi*, *Modiola scalprum*, and *Gryphœa cymbium*, and are about 250 feet thick.

The Scalpa beds are well exposed in Scalpa and Raasay, and contain *Bel. paxillosus*, *Am. margaritatus*, *Am. spinatus*, *Pecten œquivalvis*, *Rhynchonella tetrahedra*, and other marlstone fossils; their thickness is 200 feet. In Mull they are represented by soft greenish sandstones, with few fossils.

**Upper Lias.**—As elsewhere this division consists of shales with much pyrites and jet; the lower portion yields *Am. serpentinus* and *Am. radians*, and the upper beds *Am. communis*, with *Belemnites Voltzii* and *Posidonomya Bronnii*. Sections are generally obscured by slips and grass, but the thickness averages from 75 to 80 feet.

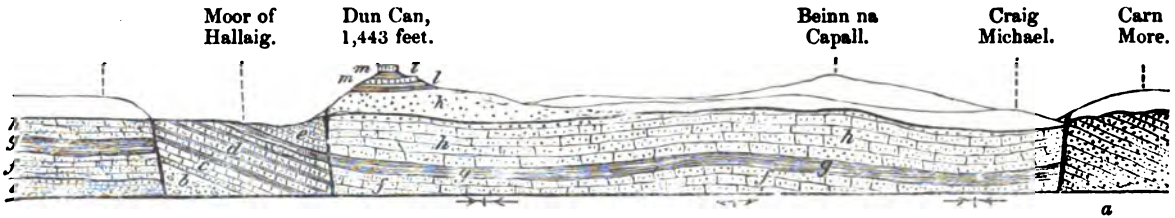



Fig. 66. Cliff section on the east side of Raasay (Professor Judd). Distance about 5 miles.

Oolitic.
- *m*. Tertiary Lavas.
- *l*. Estuarine Shales.
- *k*. Sandstones.
- *h*. Inferior Oolite.

Liassic.
- *g*. Upper Lias.
- *f*. Scalpa Beds.
- *e*. Pabba Shales.
- *c, d*. Lower Lias.

- *b*. Trias.
- *a*. Torridon Sandstone (? Cambrian).

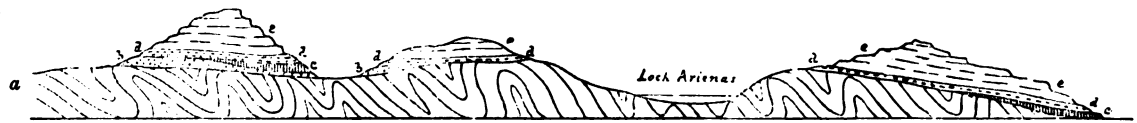



Fig. 67. Diagrammatic section through part of Morvern (after Professor Judd).

- *e*. Tertiary Lavas.
- *d*. Cretaceous Rocks.
- *c*. Jurassic Rocks.
- *b*. Triassic Rocks.
- *a*. Archæan Gneiss.

### 7. *North-East of Scotland.*

Strata of Lower Jurassic age are known only at one locality, namely, in the reefs below Dunrobin Castle on the coast of Sutherland, where they rest upon the Trias and dip N.N.E.

**Rhætic ?**—The basement beds are coarse sandstones and conglomerates, with pebbles derived from the sandstones and chert-rock of the underlying Trias; but without fossils. They graduate upward into the overlying estuarine beds, but their precise age is a matter of doubt. Their thickness is unknown, but considerable.

**Lower and Middle Lias.**—The succeeding beds are clearly of estuarine origin, consisting of sandstones and shales with thin layers of clay and coal, the whole attaining a thickness of between 400 and 500 feet; no fossils have been found except in the uppermost beds, where a few dwarfed *Gryphæa* and *Cardinia* prove the occasional presence of salt water. As these beds are overlain by clays with *Am. oxynotus*, they must be the estuarine equivalents of the greater part of the English Lower Lias.

The marine beds above exhibit the following succession:—

| | Feet. |
|---|---|
| 3. Dark blue micaceous clays, with septaria, *Am. brevispina*, *Am. Jamesoni*, *Cardium truncatum*, *Gryphæa cymbium*, and *Terebratula punctata* . . . . . | 80 |
| 2. Micaceous sandstones and clays, with *Gryphæa obliqua*, *Rhynch. variabilis*, and *Belemnites acutus* . . . . . | 40 |
| 1. Blue clays and impure limestones, with *Am. oxynotus*, *Am. caprotinus*, *Bel. acutus*, *Cardinia hybrida*, *Lima pectinoides*, and *Gryphæa obliqua* . . . . . | 60 |

Of these stages 1 and 2 are regarded as Lower Lias (zone of *Am. oxynotus*), while 3 is certainly the lower part of the Middle Lias (zones of *Am. armatus*, *Jamesoni*, and *capricornus*). No higher beds are seen, but their former existence is proved by the occurrence of boulders of calcareous sandstone, like those of the western coast, in the Boulder Clays of Moray and Elgin. These boulders enclose such fossils as *Belemnites paxillosus*, *Am. actæon*, *Modiola scalprum*, *Avicula inæquivalvis*, and *Panopæa elon-*

*gata*, and others which occur in the Scalpa sandstones of the west coast. It is quite possible indeed that such rocks (of Marlstone age) may still exist *in situ* beneath the vast masses of glacial clay[1] which mantle the surface of Elginshire.

No proof that Upper Lias was ever deposited on this coast has yet been discovered; and no fossils of that division occur in the Boulder Clays.

### § B. Middle Jurassic Series.

**Subdivisions and their Correlation.**—This part of the Jurassic system consists of a variable series of oolitic limestones and marly clays, none of the strata continuing long of the same thickness, and many beds thinning out altogether within comparatively short distances. The most persistent stratum is that known as the Cornbrash, which lies at the summit of the series. The beds which appear in different districts have for the most part received local names, and the correlation of these subdivisions is not by any means an easy matter. The results of the work done in this field are embodied in the following table, which shows the members of the series in five different sections of their range across England.

| Dorset and Somerset. | Gloucester and Wilts. | Oxford and Northampton. | Rutland and Lincoln. | Yorkshire. |
|---|---|---|---|---|
| Cornbrash. | Cornbrash. | Cornbrash. | Cornbrash. | Cornbrash. |
| Forest Marble. | Forest Marble. | Thin. | Gt. Ool. Clay. | Upper Estuarine group. |
| Great Oolite and Fuller's Earth. | Great Oolite. | Great Oolite. | Great Oolite. | Absent. |
| | Stonesfield Slate. | Estuarine Beds. | Estuarine Beds. | Absent. |
| | Fuller's Earth. | Absent. | Absent. | Absent. |
| Inferior Oolite. | Inferior Oolite. | Absent. | Lincolnshire Limestone. | Scarborough Oolites. |
| Cephalopoda Bed. | Pea Grit and Cephalopoda Bed. | Northampton Sand. | Northampton Sand. | Estuarine Beds and Dogger. |

These several members are generally grouped under two heads: (1) the Inferior Oolite, which may be called the Glevonian, from its great development in Gloucestershire;

[1] Judd, "Quart. Journ. Geol. Soc.," vol. xxix. p. 155.

(2) the Great Oolite or Bathonian (Bath Oolite). This grouping is as follows:—

| | |
|---|---|
| Great Oolite (Bathonian.) | Cornbrash. |
| | Forest Marble. |
| | Great Oolite. |
| Inferior Oolite (Glevonian.) | Fuller's Earth (chief part). |
| | Inf. Oolite Limestones. |
| | Basement Beds. |

In describing the stratigraphy of this series, we shall consider separately each of the districts mentioned in the above table.

**Geographical Range.**—This series, like the Lias, ranges completely across England from Dorset to Yorkshire. It occupies the Dorset coast between Bridport and Weymouth, and runs inland by Yeovil, Sherborne, and Bruton, to the Mendips. In Gloucestershire it forms the well-known scenery of the Cotteswolds, and spreads over a considerable width of country. Thence it passes through the counties of Oxford, Northampton, Rutland, and Lincoln, forming the long escarpment known as the "cliff" in Lincolnshire, which runs due north from Grantham by Ancaster, Navenby, Lincoln, and Kirton to the Humber.

In South Yorkshire it makes but little show, the beds being thin, but they thicken out north-west of Malton, sweeping round to the north of Helmsley and forming the high ground of the Yorkshire Wolds, which range from west to east, and terminate in the cliffs between Whitby and Scarborough.

Rocks belonging to this series occur in Skye and several other islands on the west coast of Scotland; they also form a narrow strip of ground on the east coast of Sutherland.

No beds of this age have been found in Ireland.

### Life of the Period.

**Marine Fauna.**—The fauna of the Middle Jurassic rocks is closely related generically to that of the Lias, though only about sixty species actually pass from one for-

mation to the other. The fauna of the Oolitic Limestones differs from that of the Lias principally in the relative abundance of Corals, Echinoderms, and Gasteropods. This, however, is sufficiently explained by the fact that these limestones were evidently formed in the neighbourhood of coral-reefs, such reefs at the present day always abounding in sea-urchins and univalve shells. Brachiopoda, too, are individually very abundant, though the number of species is not greater than in the Lias, and the genera are the same, except that *Leptæna* and *Spiriferina* do not occur.

Among Gasteropods a few new genera make their appearance, such as *Bulla*, *Cirrus*, and *Emarginula*, but the most important introductions are the Echinoderms *Clypeus*, *Collyrites*, *Echinobrissus*, *Hemicidaris*, *Holectypus*, *Hyboclypus*, *Pygaster*, *Polycyphus*, *Pygurus*.

The number of species obtained and described from this series up to 1884 amounted to 1883. The following are those which characterize the five principal divisions in the south-western counties:—

## Fossils of the Cephalopoda Bed.

*Brachiopoda.*—Rhynchonella cynocephala.

*Lamellibranchs.*—Hinnites abjectus, Pholadomya fidicula, Perna rugosa, Trigonia striata.

*Cephalopoda.*—Ammonites opalinus, Am. striatulus, Am. variabilis, Belemnites compressus, Bel. irregularis, Nautilus inornata.

## Fossils of the Inferior Oolite.

*Actinozoa.*—Anabacia hemispherica, Thecosmilia gregaria.

*Echinodermata.*—Collyrites ringens, Stomechinus germinans, Pygaster semiplicatus.

*Brachiopoda.*—Rhynchonella spinosa, Terebratula fimbria, Ter. Phillipsii, Ter. sphæroidalis.

*Lamellibranchs.*—Astarte elegans, Gresslya abducta, Gryphæa subloba, Ostrea flabelloides, Lima pectiniformis, Pholadomya fidicula, Trigonia costata.

*Gasteropoda.*—Cirrus nodosus, Pleurotomaria ornata, Chemnitzia procera, Nerinæa terebræformis.

*Cephalopoda.*—Ammonites Murchisoniæ, Am. Sowerbyi, Am. Humphriesianus, Am. Parkinsoni (in zones from below upwards), Belemnites giganteus, Nautilus truncatus.

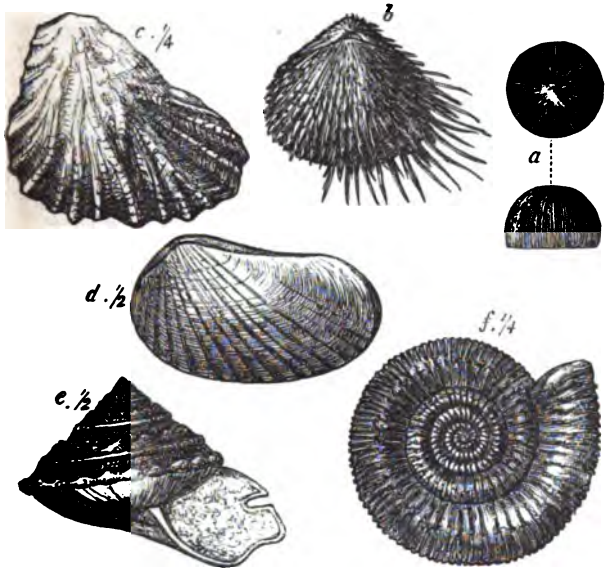



Fig. 68. Inferior Oolite Fossils.

*a.* Anabacia hemispherica.
*b.* Rhynchonella spinosa.
*c.* Ostrea flabelloides.
*d.* Pholadomya fidicula.
*e.* Pleurotomaria ornata.
*f.* Ammonites Humphriesianus.

## Fossils of the Fuller's Earth.

*Lamellibranchs.*—Ostrea acuminata, Goniomya literata, Ceromya concentrica, Gervillia acuta (all also in Inf. Oolite).

*Brachiopoda.*—Terebratula ornithocephala, Rhynch. varians.

*Gasteropoda.*—Alaria Phillipsii.

## Fossils of the Great Oolite.

*Actinozoa.*—Isastrea explanata.
*Echinodermata.*—Hemicidaris minor.

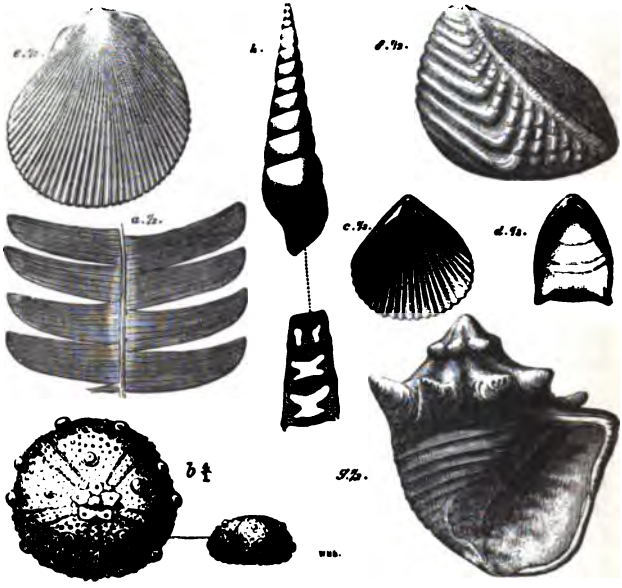


Fig. 69. Great Oolite Fossils.

| | |
|---|---|
| *a.* Pterophyllum comptum. | *e.* Lima cardiiformis. |
| *b.* Hemicidaris minor. | *f.* Trigonia Goldfussii. |
| *c.* Rhynchonella concinna. | *g.* Purpuroidea Morrisii. |
| *d.* Terebratula digona. | *h.* Nerinæa Voltzii. |

*Brachiopoda.*—Terebratula maxillata, Ter. digona, Rhynchonella obsoleta, Rh. concinna.

*Lamellibranchiata.*—Lima cardiiformis, Trigonia Goldfussii, Tr. impressa, Ostrea Sowerbyi, Pholadomya acuticosta.

*Gasteropoda.*—Purpuroidea Morrisii, Nerinæa Voltzii, Patella rugosa, Nerita costulata.

*Cephalopoda.*—Nautilus Baberi.

*Fish.*—Strophodus magnus, Pholidophorus minor.

*Reptiles.* — Teleosaurus brevidens, Rhamphorhynchus Bucklandi.

*Mammals.* — Amphitherium Prevostii, Stereognathus ooliticus, Phascolotherium Bucklandi.

## Fossils of the Forest Marble and Cornbrash.

*Actinozoa.*—Anabacia orbulites (passes to Cornbrash).

*Echinodermata.* — Apiocrinus Parkinsoni, Acrosalenia spinosa, A. hemicidaroides, Holectypus depressus.

*Brachiopoda.* — Terebratula intermedia, Ter. Bentleyi, Ter. coarctata.

*Lamellibranchs.*—Avicula echinata, A. costata, Pecten arcuatus, Lima duplicata, Myacites securiformis.

*Gasteropoda.*—Chemnitzia vittata, Purpuroidea ornata, Patella cingulata, Amberleya nodosa, Cylindrites acutus.

*Cephalopoda.*—Ammonites discus, Am. Herveyi.

**Terrestrial and Freshwater Fauna.**—The estuarine beds which occur occasionally in these rocks furnish us with some interesting remains of these faunas. The borders of the rivers and estuaries must have been clothed with a dense vegetation, ferns of the genera *Pecopteris, Sphenopteris, Glossopteris, Tæniopteris;* Cycads of many genera, *Cycadites, Zamites, Pterophyllum, Otozamites,* &c.; Coniferous trees such as *Thuyites, Pinites,* and *Brachyphyllum,* with others resembling the modern *Araucaria.* Among this vegetation insects abounded, such as Beetles, Flies, and Dragon-flies.

In the water lived Molluscs of the genera *Cyrena, Anodon,* and Crocodiles of the Gavial type, *Teleosaurus, Steneosaurus,* and *Streptospondylus.*

On land there were small Marsupials, *Amphitherium* similar to the insectivorous Myrmecobius of Australia, *Amphilestes* and *Phascolotherium* (fig. 70), related to the Opossums, and *Stereognathus,* whose affinities are doubtful.

The huge Dinosauria, *Megalosaurus* and *Ceteosaurus*, were terrestrial reptiles, the former carnivorous and the latter probably a vegetable feeder; in both the hind legs are much longer than the fore limbs. There is little doubt that they habitually walked on their hind legs alone.

The Pterosaurians (*Pterodactylus* and *Ramphorhyncus*) were lizards with bat-like wings and a light skeleton like that of a bird, but their jaws were furnished with sharp teeth.

## STRATIGRAPHY.

### 1. *Dorset and Somerset.*

**Inferior Oolite Group.**—The lowest beds of this group are well exposed on the coast near Burton Bradstock, where the cliff section is as follows:—

| | | Feet. |
|---|---|---|
| Inferior Oolite. | Fuller's Earth (lower part) . . . | |
| | Limestones with *Am. Parkinsoni*, and a bed full of *Ter. sphæroidalis* at base . | 5 |
| | Limestones with *Am. Humphriesianus* . | 3 |
| | Cephalopoda Bed (*Am. opalinus*) . . | 4 |
| Upper Lias. | Sands with *Am. jurensis* . . . | 100 |

The basement zone consists of a brown marly ironshot limestone, and is called the "Cephalopoda Bed," from the abundance of *Ammonites*, *Belemnites*, and *Nautili* which it everywhere contains (see p. 318). It is here in two beds, with a clay parting and a layer at the base full of *Belemnites*. This zone is continuous throughout the district.

The overlying limestones represent the upper portion of the Inferior Oolite, the lower zones (of *Am. Sowerbyi* and *Am. Murchisoniæ*) being absent near Burton, though represented inland near Sherborne and Bradford Abbas, and thence northward through Somerset; the thickness of the beds gradually increases till between Frome and Bath this limestone division is 60 feet thick. Near Sherborne and elsewhere it is quarried for building stone.

The Fuller's Earth attains its maximum development in Dorset, being 400 feet thick. It is a marly clay, generally

of a greenish or yellowish grey, but sometimes blue; it contains many beds of the peculiar soft greasy kind of clay which is used for fulling purposes (whence the name); near the middle there are often beds of rubbly limestone, which are called Fuller's Earth rock. It rapidly thins northward, and in Somerset is only from 150 to 120 feet.

**Great Oolite Group.** — Unless represented by the uppermost beds of the Fuller's Earth, the Stonesfield slate and Great Oolite limestone are absent in Dorset. The Great Oolite commences as a definite band near Frome (with the Bradford Clay above it), and thickens northward till it is some 80 feet thick near Bath, where it includes the well-known freestone called Bath Stone, and consists of three members as below:—

| | Feet. |
|---|---|
| Upper Rags—shelly and oolitic limestones | 20 to 50 |
| Fine Freestones, oolitic | 10 „ 30 |
| Lower Rags—coarse shelly limestones | 10 „ 40 |

The Forest Marble group is very thick in Dorset (450 feet). It is formed of numerous beds of fissile limestone divided by seams of clay. In Somerset it is not more than 100 feet thick, and includes some beds of sand and sandstone. Near Frome, Bradford, and Farleigh, the Great Oolite is separated from the Forest Marble by a deposit of pale grey marly clay, which is known as the Bradford Clay, and is celebrated for the abundance of *Apiocrinus Parkinsoni*. This clay contains seams of brown limestone and calcareous sandstone similar to those of the Forest Marble, and it yields many of the same fossils, such as *Avicula costata*, *Terebratula digona*.

The Cornbrash is a coarse rubbly ferruginous limestone of a bluish-grey colour, weathering rusty-brown. In Dorset it is about 40 feet thick.

### 2. *Gloucester and Wilts.*

**Inferior Oolite Group.**—In this district are the classical sections of the Inferior Oolite at Leckhampton and Cleeve Hill, near Cheltenham, where the following beds are distinguished:—

| | Feet. |
|---|---|
| Ragstones or Trigonia grits, coarse shelly limestones, zone of *Am. Parkinsoni* | 38 |
| Upper Freestones, with *Am. Humphriesianus* | 34 |
| Oolite marl, with *Terebratula fimbria* | 7 |
| Lower Freestones, without fossils | 147 |
| Pea-grit or Pisolite, with a coarse brown ferruginous rock at base, zone of *Am. Murchisoniæ* | 38 |
| Brown marly rock = the "Cephalopoda Bed" (zone of *Am. opalinus*) | 5 |
| | 269 |

At other localities some of the beds between the Pea-grit and the Upper freestones contain *Am. Sowerbyi, Terebratula Eudesii, Astarte excavata,* and *A. elegans.* In passing to the east all the freestone beds thin out, and the ragstones only remain above the zone of *Am. Murchisoniæ.*

The Fuller's Earth is 120 feet thick at Wooton-under-Edge, 70 at Stroud, from 40 to 30 near Cheltenham, and dies out altogether near Barrington in the valley of the Windrush. *Ostrea acuminata* and *Rhynchonella concinna* are common fossils.

**Great Oolite Group.**—The Great Oolite limestone, which forms such a conspicuous feature near Bath and Corsham, maintains its importance through Gloucester. At its base are two or three feet of sandy calcareous shale, in which *Trigonia impressa* is a common fossil; these are the equivalents of the "Stonesfield slate," so named from Stonesfield, in Oxfordshire, where they are largely quarried for roofing-slates, though properly speaking they are laminated stone and not *slate.* They are also quarried near Cheltenham and Stow in Gloucestershire, but the beds are rarely more than four feet thick. The ragstones and limestones of the main mass of Great Oolite are some 60 feet thick at Minchinhampton and Northleach. The lower beds are coarse sandy or oolitic limestones, with more or less oblique lamination; the higher beds are white marls and compact limestones in even layers.

The Bradford Clay becomes very thin north of Bath, but is traceable through the district. The Forest Marble is also much reduced in thickness, being some 40 feet thick between Cirencester and Northleach, and still less on the borders of Oxfordshire. It is worked for slates and paving-

flags. The Cornbrash is persistent at the summit, but is seldom more than 10 to 15 feet thick.

### 3. *Oxford and Northampton.*

**Inferior Oolite Group.**—In this district the Inferior Oolite is reduced to its minimum thickness, but certain portions of the Cotteswold group can be traced as far east as Chipping Norton and Fawler. At these places Mr. E. A. Walford has recognized the following beds:[1]—

| | Feet. |
|---|---|
| E. The Chipping Norton limestone, grey or cream-coloured, often siliceous | 20 |
| D. Sandy and marly limestones, *Am. Parkinsoni* | 5 |
| $C^2$. The Clypeus grit, a rubbly oolitic or pisolitic rock, with *Clypeus Plottii* and *Am. Parkinsoni* | 15 |
| $C^1$. Rubbly and marly limestone, with *Astarte minima*, *Trigonia angulata*, and corals (zone of *Am. Humphriesianus*) | 3 |
| B. Cream-coloured oolitic limestones, *Am. Sowerbyi*? | 12 |
| A. Sandy blue-hearted limestones, *Am. Murchisoniæ* and *Rhynch. cynocephala* | 5 |

At some localities near Fawler the lower limestones are absent, and the basement bed of the Clypeus grit ($C^1$) rests directly on the Upper Lias. This bed contains blocks of limestone covered with oysters and pierced by *Lithodomi*, and Mr. Walford thinks these are portions of the Freestone beds which had been originally formed over Oxfordshire, but were subsequently broken up and destroyed before the deposition of the Clypeus grit.

When we reach the valley of the Cherwell we find no limestones at all, the Inferior Oolite being represented only by 10 or 12 feet of brown sandstone and sandy ironstone, overlain by calcareous flagstones ("plank beds"), which may belong to the Great Oolite. These sandy beds thicken out rapidly again to the north-east, and in spite of the lithological dissimilarity they are considered as equivalent to the lower part of the Inferior Oolite of Cheltenham, *i.e.*, the zones of *Am. opalinus* and *Am. Murchisoniæ*. Near Northampton the succession is given by Mr. S. Sharp[2] as follows:—

[1] "Quart. Journ. Geol. Soc.," vol. xli. p. 38.
[2] "Quart. Journ. Geol. Soc.," vol. xxvi. p. 354.

| | | Feet. |
|---|---|---|
| Lower Estuarine. | White or grey sand, containing a plant bed . . | 12 |
| | White sand and ferruginous sandstone, with shelly calcareous beds, very variable, up to . . | 30 |
| Ironstone Beds. | Coarse oolitic limestone. . . . . | 4 |
| | Sandy ironstones, with *Rhynch. cynocephala*, *Rh. variabilis*, *Ammonites bifrons* . . . . | 35 |

To these beds the name of Northampton Sand has been applied.

**Great Oolite Group.**—This group is much more persistent than the Inferior Oolite. Throughout Oxfordshire the Great Oolite is divisible into two zones:—

| | Feet. |
|---|---|
| 2. White limestones, often oolitic . . | 20 to 30 |
| 1. Shelly limestones and marls, with the Stonesfield Flags or "Slate" at the base . . . . . | 25 to 35 |

Fig. 70. Marsupials from Stonesfield.

1. Phascolotherium Bucklandi.
2. Amphitherium Broderipii.

The jaws are of the natural size, above each are enlarged views of the molar teeth.

The Stonesfield Beds have yielded a remarkable assemblage of fossils, notably the small Marsupials *Amphitherium*, *Phascolotherium*, &c., the Reptiles *Megalosaurus*, *Teleosaurus*, Fish of several genera, Ferns, Cycads, and Conifers among plants, and a large number of Mollusca. (See Phillips, "Geology of Oxford," p. 168.)

As the lower zone of the Great Oolite is traced into Northampton, it is found to pass into a set of sands and clays which are called the Upper Estuarine series by Mr. Sharp. In the absence of any Inferior Oolite limestone these beds rest upon the Lower Estuarine series of the Northampton Sand, but the two estuarine groups are sharply divided

from one another, the lowest bed of the upper group being a layer of ironstone nodules, which rest on an eroded surface of the lower sands, as in fig. 71.

The Bradford Clay and Forest Marble thin out and are absent for a space in Oxford and Bucks, where the Cornbrash immediately overlies the Great Oolite; but near Blisworth and Northampton a thin bed of clay occurs in their place, and this thickens northward to about 20 feet. It contains *Placunopsis socialis* and *Ostrea Sowerbyi*, but few other fossils.

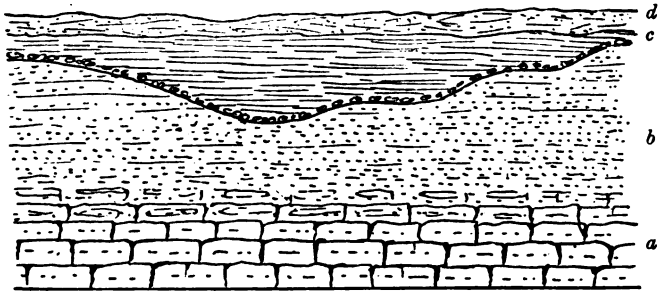



Fig. 71. Section in Pit near Northampton.

*d*. Soil and Drift.
*c*. Upper Estuarine clays.
*b*. White sand passing into
*a*. Sand-rock (Lower Estuarine).

### 4. *Rutland and Lincoln.*

**Inferior Oolite Group.**—The Northampton Sand continues as the lowest member of this group, and consists, as in Northampton, of ironstone at the base, passing up into yellow sands, which are succeeded by white sands and pale clays (Lower Estuarine beds). Between these and the Upper Estuarines a thin wedge of limestone sets in, commencing in the valley of the Welland, and rapidly thickening northwards it becomes the important formation known as the Lincolnshire Limestone, which in South Lincolnshire is not less than 150 feet thick.

At its base in South Lincolnshire are some beds of fissile sandy limestone, which form a passage from the Lower Es-

tuarine Beds; these contain ferns (*Polypodites Lindleyi*), with *Lucina Wrightii, Hinnites abjectus, Pecten demissus, Trigonia compta, Astarte elegans*, and *Pterocera Bentleyi*, but no Ammonites. At Collyweston (near Stamford) these beds are 12 feet thick, but they thin northward and are hardly distinguishable at Ancaster, where the beds seen are—

| | Feet. |
|---|---|
| Lincolnshire limestone . . . . . | 100 |
| Course of sandy stone . . . . . | 1 |
| Purple clays and white sands (Lower Est. Beds) . | 8 |
| Sandy ferruginous rock (Ironstone) . . . | 10 |

The Lincolnshire limestone frequently contains beds in which corals are very abundant, and which have evidently been accumulated in the near neighbourhood of coral-reefs; the upper layers, too, invariably exhibit much current bedding; Ammonites are rare, but *Am. Murchisoniæ*, *Am. Sowerbyi*, and *Am. subradiatus*, have been found; Echinoderms are not uncommon; Gasteropods (*Natica, Nerinæa, Patella, Pleurotomaria, Trochus, Trochotoma*) are common; *Rhynchonellæ* and Lamellibranchs of many species are abundant. The fauna has eminently a shallow-water and coral-reef facies, and in point of time the limestone appears to be the representative of the lower Gloucestershire freestones (zone of *Am. Sowerbyi*) with the Oolite marl; its uppermost portion (where thickest) may possibly represent the zone of *Am. Humphriesianus*, but that fossil has never been found in it. The Ragstone division and the Fuller's Earth are certainly absent, and there is evidence of a gap with erosion between the Limestone and the overlying Great Oolite in Rutland and Northampton.

The Lincolnshire limestone affords excellent building stone, which is largely quarried at Ketton, Casterton, Stamford, Corby, Ancaster, Lincoln, and other places.[1] In North Lincolnshire its thickness again lessens to about 60 feet.

**Great Oolite Group.**—This group consists of four

[1] See "Mems. Geol. Survey, Geology of Rutland" (Judd), and "Geology of S.W. Lincolnshire" (Jukes-Browne).

members, which are persistent through the whole district, though they vary somewhat in thickness; they are—

| | Feet. |
|---|---|
| 4. The Cornbrash . . . . | about 15 |
| 3. The Great Oolite clays . . . | „ 20 |
| 2. The Great Oolite limestone . . | „ 20 |
| 1. The Upper Estuarine beds . . | „ 30 |

The Upper Estuarine beds consist of white, blue, green, and variegated clays, with seams of lignite and occasional courses of sandy stone; the basement bed is a brown ferruginous nodular sandstone, which rests unconformably upon the Lincolnshire limestone in Rutland and Northampton, though in Lincolnshire no such evidence of erosion has been observed. The fossils are sometimes marine, sometimes estuarine forms (*Cyrena*, &c.).

The Great Oolite limestone consists of soft white marly limestones, separated by layers of marly clay. The prevalent fossils are *Ostrea Sowerbyi*, *O. subrugulosa*, *Homomya gibbosa*, and *Clypeus Mülleri*.

The Great Oolite clays are of many colours, blue, green, yellow, and purple; the only fossils are *Placunopsis socialis* and the oysters above mentioned.

The Cornbrash is as usual full of fossils; *Holectypus depressus*, *Echinobrissus clunicularis*, *Avicula echinata*, and *Ammonites Herveyi* are characteristic and common.

### 5. *Yorkshire.*

**Inferior Oolite Group.**—In South Yorkshire the Middle Jurassic series is quickly overstepped by the Cretaceous rocks, but beds of the Lincolnshire type are seen near South Cave. When they again emerge in North Yorkshire the series has undergone much transformation, and the mass of the Inferior Oolite consists of estuarine sandstones and shales 300 or 400 feet thick. Marine beds, however, occur at the top and bottom, and also as a thin zone in the midst of the Estuarine series, the succession being as follows, and the thicknesses those in the cliff sections:—

| | Feet. |
|---|---|
| 5. Scarborough limestone . . | 20 to 60 |
| 4. Estuarine beds . . . | 50 to 100 |
| 3. Millepore beds (marine) . . | 20 to 40 |
| 2. Lower Estuarine series . . | 280 |
| 1. The "Dogger," and Blue Wyke sands . . . . . | 40 to 80 |

1. Above the Lias (*Am. jurensis* zone), at Blue Wyke and elsewhere, are yellow and grey micaceous sands containing *Ammonites aalensis*, *Lingula Beanii*, and *Rhynchonella cynocephala*. These are regarded by Messrs. Blake and Hudle-

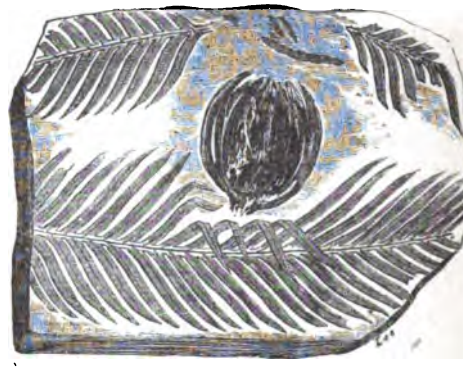


Fig. 72. Leaves and Fruit of Cycadites lanceolata ($\frac{1}{8}$), Gristhorpe Bay, Scarborough.

ston as representing the *opalinus* zone. They are surmounted by the "Dogger," a sandy ironstone often oolitic, which contains many fossils and may be regarded as the equivalent of the Northampton ironstone.

2. The Lower Estuarine series is very thick, and includes the "Great Sand-rock" which is largely used as a building-stone in Eskdale. On the coast beds appear in the cliffs from Robin Hood's Bay to Huntcliff. The shales and oolitic ironstones contain plant remains in some abundance.

3. The Millepore beds consist of a hard calcareous sandstone with the Millepore *Spiropora straminea*, overlain by shales and sandstones containing *Trigonia recticosta*, *Ce-*

*romya Bajociana, Gervillia lata, Pygaster semisulcatus*, and other fossils.

4. The Middle Estuarine series consists of shales and sandstones, with thin layers of coal varying from two to eighteen inches in thickness. The "plant bed" of Gristhorpe Bay has yielded fine specimens of Ferns (*Pecopteris, Phlebopteris, Glossopteris, Tæniopteris*, &c.), the Cycads *Pterophyllum, Cycadites*, and *Otozamites*, and the Horsetail *Equisetites columnaris*.

5. The beds termed the Scarborough Limestone are grey, shaly limestones, often ferruginous; they contain *Ammonites Humphriesianus, Gervillia acuta, Avicula Braamburiensis*, &c. They form a lenticular mass, very thin at Gristhorpe, but thickening to the north-west.

Groups 3 and 4 certainly represent the Lincolnshire limestone, and the Scarborough limestone appears to be the zone of *Am. Humphriesianus*.

**Great Oolite Group.**—The limestone of the Great Oolite has entirely thinned away beneath the Cretaceous overstep, and the whole group is represented on the Yorkshire coast by shales and sandstones of estuarine origin, capped by a thin band of Cornbrash, with marine fossils.

In Gristhorpe Bay this estuarine series is 120 feet thick, consisting of marine sandstones in the lower part, and shales with thin sandstones above. Further north they are over 200 feet thick. A few ferns (*Cyclopteris* and *Pecopteris*) are the only fossils.

The Cornbrash is very thin, only five or six feet, but has the usual characters, being a grey, rubbly ironshot limestone full of the ordinary fossils, among which are *Ammonites Herveyi, Avicula echinata, Lima rigidula*, and *Waldheimia lagenalis*.

### 6. *West of Scotland.*

At certain localities in the Inner Hebrides strata occur between the Lias and the Tertiary lavas which are comparable to our English Oolites, more especially to those of the Yorkshire area (see figs. 66 and 67).

**Inferior Oolite Group.** — "Rocks of this age,"

says Professor Judd, "must have originally had a very wide distribution, for traces of them are found at various points from the Shiant Isles in the north to Ardnamurchan in the south. The best exposures of their strata, however, are those which occur in the islands of Skye and Raasay."[1] Here the succession is as follows:—

| | Feet. |
|---|---|
| Limestones almost wholly made up of comminuted shells; *Ostrea Sowerbyi*, *Waldheimia lagenalis* = ? zone of *Am. Parkinsoni*. | 45 |
| Beds of white sandstone, with thin shaly bands containing remains of Ferns and Cycads . . . . . | 60 |
| Beds of sandstone and shale, the former passing into shelly limestones; *Am. Humphriesianus*, *Bel. giganteus* . . . . | 160 |
| Sandy micaceous shales alternating with calciferous sandstones; *Am. Murchisoniæ*, *Am. corrugatus*, *Bel. giganteus*, *Lucina Wrightii*, &c. . . . . | 120 |
| | 385 |

**Great Oolite Group.**—The Inferior Oolite of Skye and Raasay is succeeded by a considerable thickness of estuarine strata, which occupy the position of the Great Oolite and are probably not less than 500 feet thick, although in those islands they are imperfectly exposed; southwards in the islands of Eigg and Muck this group acquires still greater proportions, and are exposed in clearer sections.

A. The lowest beds are fine conglomerates and shelly limestones full of freshwater shells, but containing also remains of *Plesiosaurus*, Turtles, and other reptiles; above these are black shales and limestones abounding in *Cyprides*, fish remains, and shells of *Cyrena*, *Cyclas*, and *Paludina*. Thickness of the whole group, 200 feet.

B. Grey and white sandstones, sometimes passing into calcareous grits, with large concretionary siliceous masses; current-bedding and ripple-marked surfaces are frequent, but excepting plant remains fossils are rare. Thickness probably more than 500 feet.

C. The highest beds are black shales with thin bands of argillaceous limestone, and bands of fibrous carbonate of lime; they are sometimes crowded with *Cyrena* and *Cyclas*, and in other places with *Paludina*, *Melania*, and other

[1] "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 719.

univalves.[1] Beds entirely composed of oysters (*O. hebridica*) also occur, resembling those in the Purbeck series (see *postea*). Thickness 150 feet.

How far these estuarine strata originally extended it is impossible to say, but they clearly form part of an extensive and important formation, comparable, in many respects, to the Wealden series of the Cretaceous system.

### 7. *East of Scotland.*

Beds of Middle Jurassic age occupy a small space on the coast of Sutherland south of Brora, and form two small patches at Burgh Head and Stotfield, on the coast of Elgin. They consist entirely of estuarine strata, which are lithologically comparable to those of the Great Oolite group on the western coast. The descending succession near Brora is as follows:—

| | Feet. |
|---|---|
| "Roof bed," calcareous sandstone (Kellaway) . . . . . | |
| Coal composed of crushed *Equisetites* . . . . . | 3½ |
| Black shales, with thin coal-seams in the upper part, plants and crushed shells of *Unio*, *Ostrea*, *Cyrena*, &c., abound; also teeth and scales of fish, *Lepidotus*, *Pholidophorus*, and *Hybodus* . . . . . | 26 |
| Black, brown, and grey clays, with layers of argillaceous limestone; *Cyrena* and *Ostrea* . . . . . | 96 |
| White sandstones, with some beds of clay; in this a few obscure marine shells occur . . . . . | 110 |

The base is not seen, and whether any beds comparable to the Inferior Oolite of the west coast exist below is, therefore, unknown.

At Stotfield there are soft, greenish-white sandstones containing an assemblage of fossils which might be either of Great or Inferior Oolite age, though the presence of *Ostrea Sowerbyi*, *Tancredia axiniformis*, *Astarte rhomboidalis*, and *Pholadomya oblita* suggest Great Oolite affinities.

[1] Described by Tate in Appendix to Dr. Bryce's paper on "Skye and Raasay" in "Quart. Journ. Geol. Soc.," vol. xxix. p. 317.

### § c. Upper Jurassic Series.

**Component Strata and Geographical Range.**—The Upper Jurassic series, where fully developed, as in the south of England, consists of four groups of marine strata, two great argillaceous formations (the Oxford and Kimeridge Clays), each surmounted by a group of limestones (the Coral Rag and the Portland Beds). Above the Portland group are the Purbeck beds, a set of estuarine and terrestrial strata, which are by some united with the Wealden and placed in the Cretaceous system. The Portland and Purbeck beds of the Midland counties are, however, so intimately connected, that it would be highly inconvenient to regard the Jurassic system as terminating with the former group, for many of the Purbeck species were in existence before the Portland forms had died out.

The cliffs of the south coast near Weymouth and Portland expose good sections of all these rocks, but their inland outcrop is repeatedly concealed by the overstep of the Cretaceous strata. They appear, however, for a space near Gillingham and Tisbury, in the vale of Wardour, and again near Devizes. From Calne and Swindon their outcrop is more continuous through Oxford, Berks, and Bucks, but the limestones die out in Bucks, and only the clays remain through Bedford, Cambridge, Huntingdon, and Lincoln. In South Yorkshire they are entirely concealed by the Cretaceous overstep, but in the north of that county there is a fine development of the Oxfordian, Corallian, and Kimeridgian groups.

With regard to the eastward extension of these rocks beneath the newer systems, we have the testimony of three important borings. The Sub-Wealden boring near Battle pierced the following beds:—

| | Feet. |
|---|---|
| Lower Purbeck Beds . . . . | 180 |
| Portland Sand . . . . . | 92 |
| Kimeridge Clay . . . . . | 800 |
| Supra-coralline Beds . . . . | 300 |

A recent boring at Chatham proved Oxford clay beneath Cretaceous rocks, so that we may reasonably conclude that

this also comes in beneath the Wealden area. At Richmond, however, the whole series is absent, the only member of the Jurassic system there found being the Great Oolite. Other borings in Essex, Suffolk, and Norfolk demonstrate the complete absence of Jurassic rocks in those districts. It is probable, however, that some of the Upper Jurassic rocks originally extended over the whole of eastern England, and that their absence is due to their destruction in early Cretaceous times.

Beyond Yorkshire nothing is seen of the Jurassic rocks till we reach the coast of Sutherland, and here the Upper series is fully developed. On the west coast of Scotland only the upper part of the Oxford clay is found, covered directly by Cretaceous beds.

## Life of the Period.

The Upper Jurassic fauna is merely a continuation of that which preceded it, the genera being the same, though the species are for the most part different, only 60 species passing from the Cornbrash into the Oxford clay.

The most impressive feature of the later fauna is the abundance of reptilian remains. The Jurassic period has been termed the "age of reptiles," and these creatures seemed to have reached the climax of their dominion towards the close of the period. Their numbers and the variety of their modifications are quite extraordinary. Not only did they swarm in the seas and rivers, but they peopled the land with gigantic herbivores, and filled the air with winged forms. They thus adapted themselves for all kinds of food and all conditions of life with an elasticity of organization which is truly remarkable, and to which no parallel can be found in the subsequent history of the world, unless it is among the Australian marsupials, though no member of that order possesses powers of flight comparable to those of the Pterodactyles.

Of Upper Jurassic Reptiles, *Plesiosaurus*, *Pliosaurus*, *Ichthyosaurus*, with the Crocodiles *Teleosaurus*, *Steneosaurus*, *Dakosaurus*, and *Goniopholis* were the chief aquatic genera.

*Ceteosaurus*, *Gigantosaurus*, *Iguanodon*, *Megalosaurus*, *Omosaurus*, and *Cryptosaurus* were terrestrial Dinosaurs, and species of *Pterodactylus* were the aerial forms.

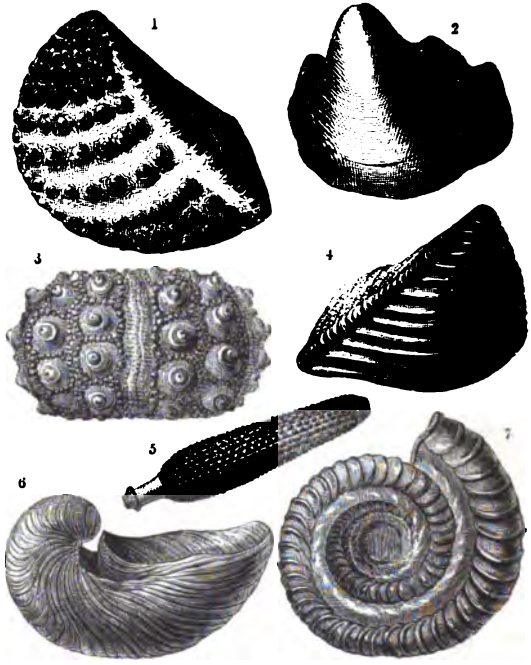



Fig. 73. A Group of Jurassic Fossils.

1. Trigonia clavellata, Coral Rag and Kim. Clay.
2. Trigonia gibbosa (cast), Portland Stone.
3 and 5. Cidaris florigemma, Coral Rag.
4. Trigonia costata, Lower Oolites, Oxford Clay, and Coral Rag.
6. Gryphæa incurva, Lower Lias.
7. Ammonites bifrons (young), Upper Lias.

The following are the species of marine invertebrates which are characteristic of each member of the series:—

## Fossils of the Oxford Clay.

*Brachiopoda.* — Waldheimia impressa, Rhynchonella socialis.

*Lamellibranchiata.*—Gryphæa dilatata, Modiola bipartita, Myacites recurva.

Fig. 74. Restored skeleton of Pterodactylus crassirostris ($\frac{1}{4}$).

*Gasteropoda.*—Alaria composita, Cerithium Damonis.

*Cephalopoda.*—Ammonites Calloviensis, Am. cordatus, Am. jason, Am. excavatus, Am. Lamberti, Belemnites Owenii, Bel. hastatus, Bel. gracilis.

## Fossils of the Corallian Group.

*Actinozoa.*—Thecosmilia annularis, Thamnastrea arachnoides, Isastrea explanata, I. concinna.

*Echinodermata.*—Cidaris florigemma, Acrosalenia decorata, Hemicidaris intermedia, Echinobrissus scutatus.

*Brachiopoda.*—Rhynchonella Thurmanni.

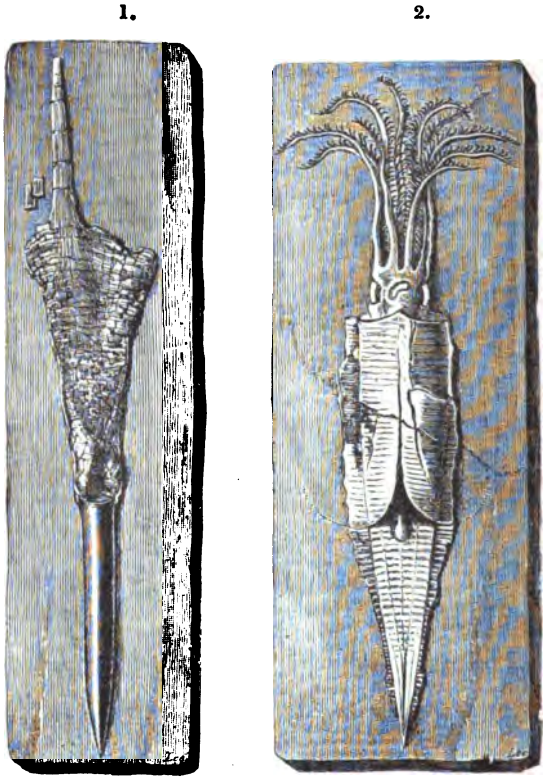



Fig. 75. Oxford Clay Fossils.

1. Belemnites puzosianus ($\frac{1}{2}$).
2. Belemnoteuthis antiquus ($\frac{1}{3}$).

*Lamellibranchiata.*—Opis corallina, Gervillia aviculoides, Pholadomya æqualis, Trigonia clavellata, Goniomya literata.

*steropoda.*—Cerithium muricatum, Phasianella striata, nitzia Heddingtonensis, Nerinæa Goodhallii.
*phalopoda.*—Ammonites perarmatus, Am. vertebralis, nnites abbreviatus.

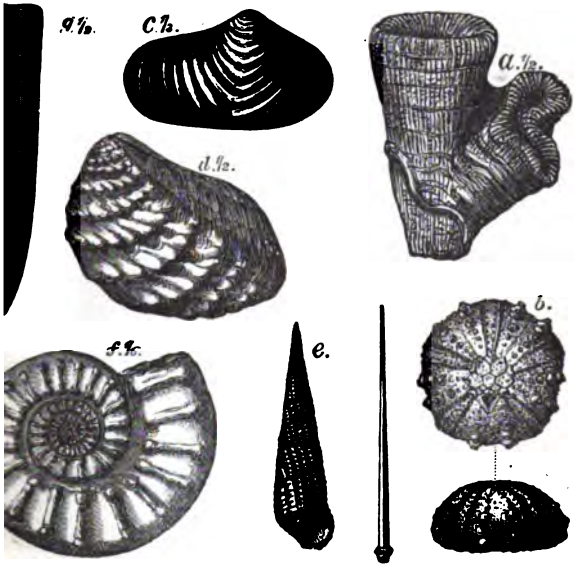



Fig. 76. Coral Rag Fossils.

Thecosmilia annularis.
Acrosalenia decorata.
Goniomya literata.
*d.* Trigonia clavellata.
*e.* Cerithium muricatum.
*f.* Ammonites perarmatus.
*g.* Belemnites abbreviatus.

## Fossils of the Kimeridge Clay.

*achiopoda.*—Discina latissima, Lingula ovalis, Rhynella inconstans.
*Mellibranchiata.*—Ostrea deltoidea, Thracia depressa, rte Hartwellensis, Trigonia monilifera, Cardium striata, Exogyra virgula.

*Gasteropoda.*—Pleurotomaria reticulata (also Oxfordian and Corallian), Littorina pulcherrima.

*Cephalopoda.*—Ammonites biplex, Am. mutabilis, Am. rotundus, Am. decipiens, Belemnites nitidus.

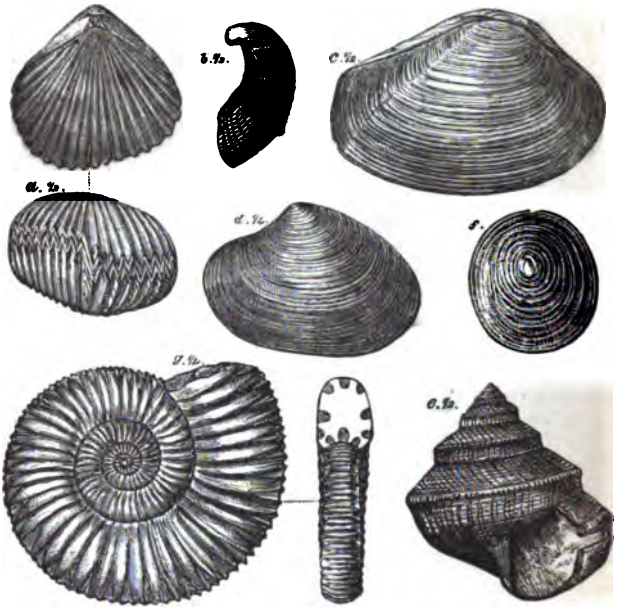


Fig. 77. Kimeridge Clay Fossils.

*a.* Rhynchonella inconstans.
*b.* Exogyra virgula.
*c.* Astarte Hartwellensis.
*d.* Thracia depressa.
*e.* Pleurotomaria reticulata.
*f.* Discina latissima.
*g.* Ammonites biplex.

## Fossils of the Portland Beds.

*Actinozoa.*—Isastrea oblonga.

*Brachiopoda.*—Waldheimia boloniensis.

*Lamellibranchiata.*—Cardium dissimile, Pecten lamellosus, Trigonia gibbosa, Lucina Portlandica, Ostrea expansa.

*Gasteropoda.*—Cerithium Portlandicum, Neritoma sinuosa, Natica elegans, Pleurotomaria rugata.

*Cephalopoda.*—Ammonites giganteus, Am. pectinatus.

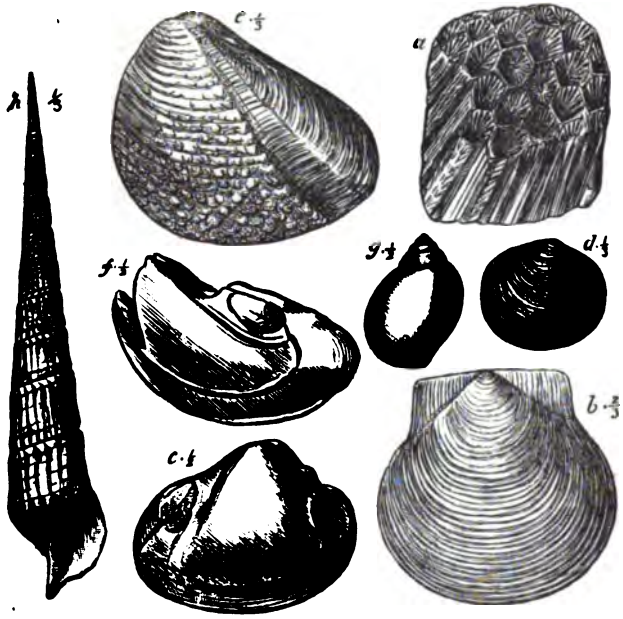



Fig. 78. Fossils of the Portland Stone.

*a.* Isastrea oblonga.
*b.* Pecten lamellosus.
*c.* Cardium dissimile (cast).
*d.* Lucina Portlandica.
*e.* Trigonia gibbosa.
*f.* Trigonia incurva (cast).
*g.* Natica elegans.
*h.* Cerithium Portlandicum.

## Fossils of the Purbeck Beds

(A terrestrial and freshwater fauna).

The following Invertebrates are characteristic :—

*Crustacea.*—Cypridea tuberculata, C. fascicularis, C. punctata, Archæoniscus Edwardsii.

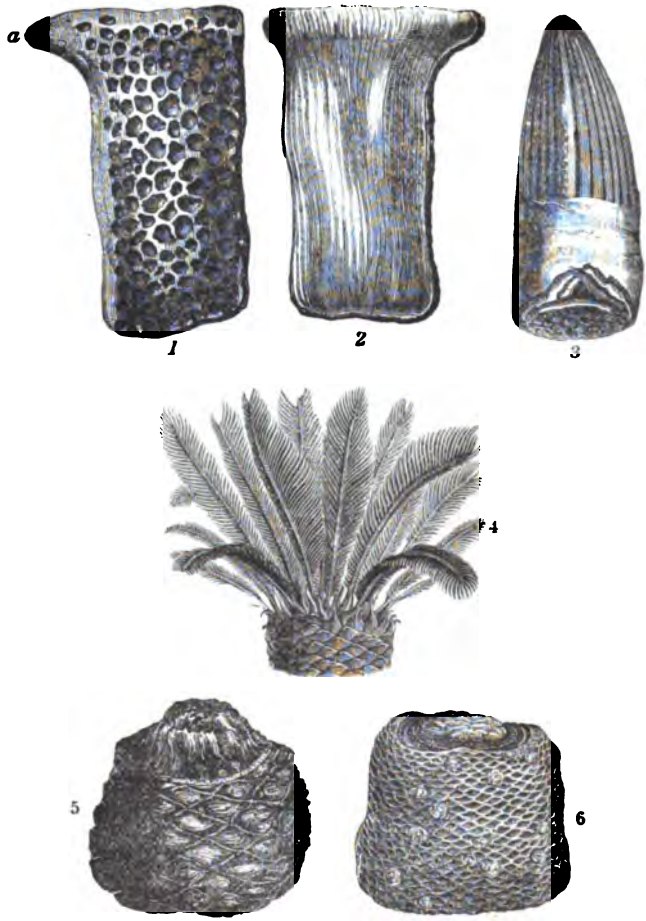



Fig. 79. Purbeck Fossils.

1, 2. Goniopholis crassidens, scutes, and (3) tooth.
4. Cycas revoluta, a living Cycad ($\frac{1}{12}$).
5. Mantellia nidiformis ($\frac{1}{12}$).
6. Mantellia cylindrica ($\frac{1}{8}$).

*Lamellibranchiata.*—Cyrena elongata, Ostrea distorta.

*Gasteropoda.* — Physa Bristovii, Paludina carinifera, Planorbis, Valvata helicoides, Limnæa physoides.

Remains of Insects are also abundant.

Among Vertebrate remains the following occur:—

*Fish.*—Lepidotus minor, Hybodus striatus, Microdon radiatus, Aspidorhyncus Fisheri.

*Reptiles.*—Goniopholis, Theriosuchus, Nannosuchus (Crocodiles), Chelone and Pleurosternon (Turtles), and Doratorhyncus (a Pterodactyle).

*Mammalia.*—12 genera and 20 species of Marsupials, of which the more important are Plagiaulax, Spalacotherium, Triconodon, Stylodon, and Amblitherium.

The most conspicuous plant is the Cycad *Mantellia nidiformis* (see fig. 79), the squat stems of which occur in the Dirt beds. The Conifers are referred to *Pinites*.

## Stratigraphy.

In the case of the Upper Jurassic rocks we need not divide their range through England into more than three sections or districts for separate consideration: the first we may call the Southern district, the beds exposed in all the southern counties as far north as the neighbourhood of Thame and Aylesbury belonging to one lithological type; the second, or Central district, includes the counties of Bedford, Huntingdon, Cambridge, and Lincoln; the third, or Northern district, contains the Yorkshire type.

### 1. *Southern District.*

**Oxford Clay.**—This clay has not yet been studied in detail, for few good exposures occur inland. It usually forms a wide tract of low ground between the ridges formed by the outcrops of the Cornbrash and Corallian Beds. In Dorset the Oxford clay is about 600 feet thick, and it appears to maintain this thickness into Oxford and Bucks.

In Wilts and Berks, there is a brownish calcareous sandstone at the base, which is generally full of fossils, and is

known as the Kellaways Rock, but it is not found either in Dorset or Oxford. Its peculiar fossils are *Gryphæa bilobata*, *Am. callovienis*, *Am. Kœnigi*, and *Am. macrocephalus*.

The mass of the Oxford clay is a stiff blue clay, or "clunch," with layers of large septarian concretions at intervals; it is probably capable of subdivision into zones, for Professor Prestwich says the lower part, north of Oxford, contains *Ammonites Duncani*, the upper part *Am. vertebralis*, while between the two there is clay with *Am. Lamberti*.

**The Corallian Group** is a variable set of beds, sands and clays with limestones above; these latter being hard form a ridge or escarpment overlooking the plain of the Oxford clay. The group is usually divisible into three stages, viz.:—

3. Upper Calcareous Grit.
2. Coral Rag.
1. Lower Calcareous Grit.

The two lower stages are everywhere well developed throughout the southern district, but the uppermost is of small importance.

Near Weymouth, in Dorset, the succession is as follows:—

| | | Feet. |
|---|---|---|
| 8. Ferruginous sandstone<br>7. Sandsfoot clay | Passage beds | 50 |
| 6. Grey marly stone (Up. Calc. grit) | | 5 |
| 5. Shelly ragstones, with *Trigonia clavellata* (Trigonia beds) | | 30 |
| 4. Osmington beds, oolitic limestones and marls | | 20 |
| 3. Bencliff grits<br>2. Nothe clay<br>1. Nothe grits | Lower Calc. grit | 80 |

The Nothe clays and grits at the base contain a mixture of Oxfordian and Corallian species, *Gryphæa dilatata* and *Ammonites cordatus*, with *Ostrea gregarea* and *Trigonia perlata*. The Osmington and Trigonia beds represent the Coral Rag, but do not contain corals. Nos. 7 and 8 are called the Supra-coralline beds by Mr. Hudleston, and are regarded as passage beds.

In Wilts, Berks, and Oxfordshire, the Lower Calcareous Grit consists of soft yellow sands, with irregular layers of

hard calcareous stone, and varies from 20 to 80 feet in thickness. The middle beds (Coral Rag) consist of shelly limestones, oolites, and pisolites, with bands containing the characteristic corals and Echinoderms. At Calne this division is 55 feet thick, only 10 feet near Faringdon, thickens again to 25 feet at Headington and Wheatley, and then gradually dies out. Throughout this tract the Upper Calcareous Grit consists of variegated sands with seams of clay; it is seldom more than five feet thick, and is sometimes entirely absent.

At Stanton St. John, north-east of Wheatley, the beds seen are:—

| | | |
|---|---|---|
| Coral Rag, with broken fossils . . | | 3 feet. |
| Calc. Grit. | Yellowish sandy clay, with *Ostrea sandalina* . . . . | 10 „ |
| | Hard grey siliceous limestone . | 6 „ |

Eastward the lower beds alone remain, and finally pass into a blue sandy clay, with *O. sandalina*, which has been traced as far as Westcot and Quainton.

**Kimeridge Clay.**—Like the Oxford clay, this formation is a difficult one to study, on account of the few inland exposures; moreover, it varies greatly in thickness, and different localities yield different assemblages of fossils. It appears to attain its maximum thickness in the extreme south, being nearly 1,000 feet in Dorset, according to Professor J. F. Blake, though other authorities make it only 600 or 700, while in Sussex (Sub-Wealden boring) 800 feet are assigned to it by Mr. Topley,[1] exclusive of 300 feet of doubtful Supra-coralline or passage beds. This great mass of clay becomes rapidly thinner as it passes northwards: at Swindon it is only 500 feet, and in Oxfordshire is believed to be little more than 100, but this sudden decrease may be partly due to the concealment of the higher beds by the overstepping Cretaceous sands and clays, for near Hartwell and Aylesbury there is a much wider outcrop of Kimeridge clay.

According to Professor J. F. Blake,[2] the Dorsetshire sec-

[1] Dixon's "Geology of Sussex," p. 152.
[2] "Quart. Journ. Geol. Soc.," vol. xxxi. p. 196.

tion, as seen in Ringstead and Kimeridge Bays, is divisible into three stages:—

3. The Upper Kimeridge Clay.
2. The Lower Kimeridge Clay.
1. The Kimeridge Passage Beds (Supra-coralline).

The (Supra-coralline) passage beds are sandy blue clays, with some thin bands of coarse sand; they contain *Ostrea deltoidea, Lima pectiniformis, Avicula œdilignensis,* with corals and *Cidaris florigemma* in the sandy beds, which repeat Corallian conditions. At Abbotsbury, near Weymouth, and again at Westbury, in Wilts, thick beds of oolitic ironstone occur, and belong apparently to this stage; at Abbotsbury it is 20 feet thick, and contains *Rhynchonella corallina* and *Waldheimia lampas.*

The Lower Kimeridge clay is about 300 feet thick; it is characterized by the presence of large septaria, and by the fossils *Am. cymodoce, Am. Berryeri, Am. decipiens, Astarte supracorallina. Exogyra virgula* and *Rhynchonella inconstans* are also present.

The Upper Kimeridge is 650 feet thick at Kimeridge; it is mainly composed of black bituminous shale, and contains *Am. biplex, Am. Thurmanni, Lucina minuscula, Cardium striatulum,* and *Discina latissima.* It is apparently this upper part of the formation which becomes so much thinner in the Midland counties; at Swindon and Hartwell there are bluish sandy clays below the Portland sand which seem to represent the Upper Kimeridge.

**Portland Beds.**—Like the Kimeridge clay these beds are thickest near the coast, and thin to the northward. They are usually divided into two stages: 1, the Portland sand; 2, the Portland stone. The former passes down into the Kimeridge clay, and has a fauna of an intermediate character. The Portland stone is a variable set of limestones, sometimes chalky, sometimes oolitic or shelly; its usual facies is purely marine, with large *Ammonites, Pectens,* and *Trigoniæ;* but occasionally beds of a more estuarine type, with *Cerithium, Neritoma,* and *Cyrena rugosa.*

The best known section is that of the Portland quarries, where the succession is as follows:—

| | Feet. |
|---|---|
| 10. The "roach," an oolitic shell limestone | 18-27 |
| 9. The "white bed," a whitish brown stone | |
| 8. The "curf," an oolite, sometimes replaced by rubbly stone and flint | |
| 7. The "base-bed," similar to the roach, but containing bands of flint | |
| 6. Limestone with *Trigoniæ*, varying in thickness, and resting on an eroded surface, sometimes cutting out No. 5 | 5-20 |
| 5. Flint and limestone rubble, 6 feet | 40 |
| 4. Chalky limestones, with frequent layers of flint | |
| 3. Stiff blue marl | 12 |
| 2. Sandy marl, with bands of calcareous stone, and a bed made up of *Exogyræ* | 43 |
| 1. Blue sandy clays seen for | 30 |
| | About 155 |

Nos. 1, 2, and 3 are the Portland sand, which at St. Albans Head is 120 feet thick; Nos. 4, 5, and 6 are known as the "flinty series;" Nos. 7 to 10 are the building stones for which Portland is so famous. At Upway, north of Portland, the flinty series is represented by massive white chalky limestones with large nodules of flint.

In the Vale of Wardour the Portland stone has about the same thickness, consisting of oolitic limestones with *Cerithium portlandicum* (18 feet), white chalk and chalky limestone (34 feet), with sandy calcareous stone at the base (20 feet); the beds below this belong to the Portland sand, but are only from 30 to 40 feet thick.

The great quarries at Swindon exhibit a remarkable section,[1] see fig. 80, the Portland beds being here divided into two distinct groups by a well-marked plane of erosion; the beds *i* to *g*, in fig. 80, contain freshwater fossils resembling those of the Purbeck series, and have at their base stones derived from the beds *d*, *e*, *f*; these *d*, *e*, *f*, are limestones, and *c* is a bed of brownish sand, all with marine Portland fossils (*Trigonia gibbosa*, *Cerithium portlandicum*, &c.). All these beds (*c* to *i*) fill a wide hollow excavated in the underlying stratum *b*, which is a grey sand including large masses of calcareous stone, and having a maximum thickness of 27 feet. Below this is a white rubbly limestone,

[1] Described by Professor Blake in "Quart. Journ. Geol. Soc.," vol. xxxvi. p. 203.

*a* (seen for 7 feet). Professor Blake regards *a* and *b* as equivalent to the lower part of the "flinty series" of Portland, and the upper beds, both marine and freshwater, as representing the upper part of the same series.

Sections outside the quarries disclose the following beds belonging to the Portland sand:—

| | Feet. |
|---|---|
| 3. Blue clay, with fossils . . . . | 20 |
| 2. Sandy glauconitic clay . . . . | 6 |
| 1. Grey sands, with calcareous "doggers" | 50 |

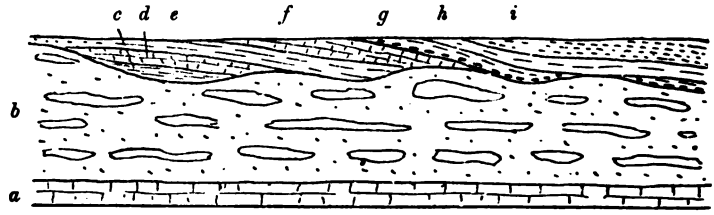



Fig. 80. Diagrammatic View of the Swindon Quarries (after Professor Blake).

In Bucks, near Hartwell and Aylesbury, these Portland sand-beds seem to have thinned out, and the Portland stone is represented by a diversified series of beds, partly marine and partly freshwater, the succession of which may be summarized as below:—

| | Feet. |
|---|---|
| 5. Thin bedded limestones and marls, with bands of calcareous shale and sand, containing *Cyprides* and freshwater fossils . | 15 |
| 4. Hard whitish limestones, with marine fossils . . . . | 6 |
| 3. Soft buff loamy sand . . . . . | 8 |
| 2. Hard grey limestone, with marine fossils . . . . . | 5 |
| 1. Soft sands, with calcareous bands, pebbles of lydianite, and derived phosphate nodules . . . . . | 6 |

No. 5 is a variable group, but rests evenly on No. 4, the shales at its base sometimes enclosing a thin limestone, with Portland fossils.

**Purbeck Beds.**—The typical Purbeck beds are only found where the Portland beds are completely developed, as in Dorset and the Vale of Wardour. They consist of

limestones, shales, black earths, and marls, in thin beds, which exhibit alternations of terrestrial, freshwater, brackish-water, and estuarine conditions; the changes from brackish to freshwater deposits being generally gradual, while the reverse changes are abrupt, indicating sudden inroads of the sea.

In Durlston Bay, near Swanage, where they are 400 feet thick, they have been divided into Lower, Middle, and Upper stages by Messrs. Forbes and Bristow, the following being a summary of the beds:—

| | | Feet. |
|---|---|---|
| Upper, 80 feet. | Grey and purple marls, with *Paludina*, not seen at Durlston Bay | 20 |
| | Shales, with beds of Paludina limestone (Purbeck marble), *Cyprides* abundant | 45 |
| | Unio beds and shelly limestones, with *Paludina* | 15 |
| Middle, 155 feet. | Alum-shales and thin limestones, with layers of gypsum, *Corbula*, *Cyrena*, *Cyclas*, &c. | 63 |
| | Hard shelly limestones, with partings of shale, fossils of marine and estuarine species | 50 |
| | Cinder bed, a mass of *Ostrea distorta* | 9 |
| | Thin limestones, marls, and shales, with remains of insects, fish, and freshwater shells; at the base is a black shale with mammalian remains | 33 |
| Lower, 170 feet. | Blue and grey shaly marls, plants, and insects | 100 |
| | Marly limestones and shales, with *Cyprides* | 36 |
| | Beds of broken slaty limestone | 15 |
| | Brown bituminous limestones, with shaly partings, and a dirt bed resting on Portland stone | 19 |
| | | 405 |

The same series can be seen in Worbarrow Bay, Mewps Bay, and Lulworth Cove, but become thinner to the westward, 250 feet at Mewps Bay, and at Ridgeway Hill only 190 feet.

The Lower Purbecks are characterized by *Cypris Purbeckensis*, the Middle by *C. fasciculata*, and the Upper by *C. punctata*.

The lowermost beds are well exposed in the quarries at Portland, and the succession is given in fig. 81. The most remarkable bed here is the upper "Dirt bed," which is a dark brown loamy earth, an actual soil or terrestrial surface, in which Cycads and Coniferous trees are still rooted; its thickness is not more than a foot, being rather

exaggerated in fig. 81. An account of this ancient submerged forest was given in vol. i. ("Physical Geology"), p. 303.

In the Vale of Wardour only Lower Purbeck (50 feet) and Middle Purbeck (20 feet) are found, succeeded by Wealden beds. At the base of the Purbeck Beds there is generally a thin bed of dark clay, and a few feet above this occurs a "dirt-bed" containing Cycads and Coniferous

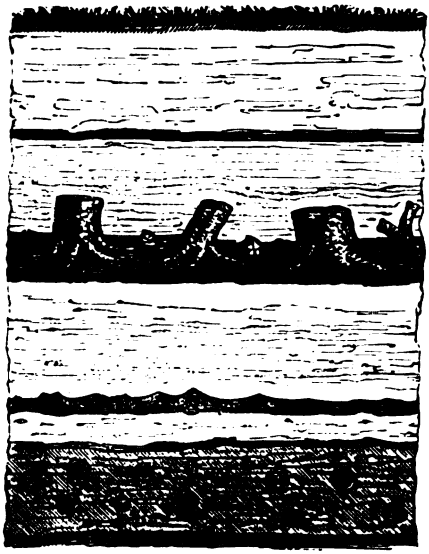

8. Shaly limestone.
7. Clay parting.
6. Shaly limestone.
5. "Dirt bed" with tree stumps.
4. The "Cap" limestone.
3. Dirt bed.
2. Skull cap. Thin layer of clay.
1. The Roach (Portland).

Fig. 81. Purbeck Beds at Portland. Total thickness about 30 feet.

wood. The oyster-bed in the Middle Purbeck here contains *Trigonia densinoda*, a species which is closely allied to the Portland *Trigoniæ*, but has some affinities with Cretaceous species.[1]

The freshwater beds of Bucks, formerly referred to the Purbeck series, are probably of Portland age (see p. 348).

[1] "Proc. Geol. Assoc.," vol. vii p. 174, and "Quart. Journ. Geol. Soc.," vol. xxxvii. p. 246.

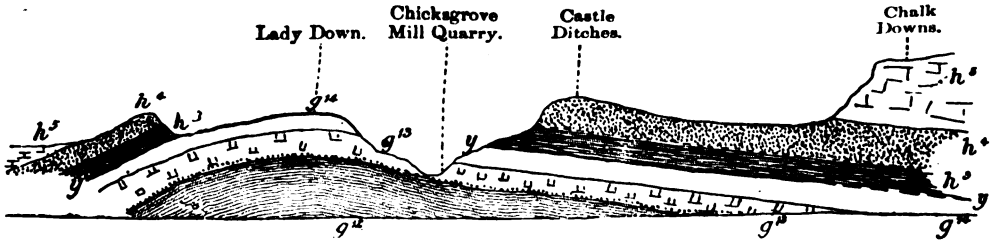



Fig. 82. Diagrammatic section across the Vale of Wardour (4 miles).

$h^5$. Chalk. $h^4$. Upper Greensand. $h^3$. Gault.
$g^{14}$. Purbeck Beds. $g^{13}$. Portland Beds. $g^{12}$. Kimeridge Clay.

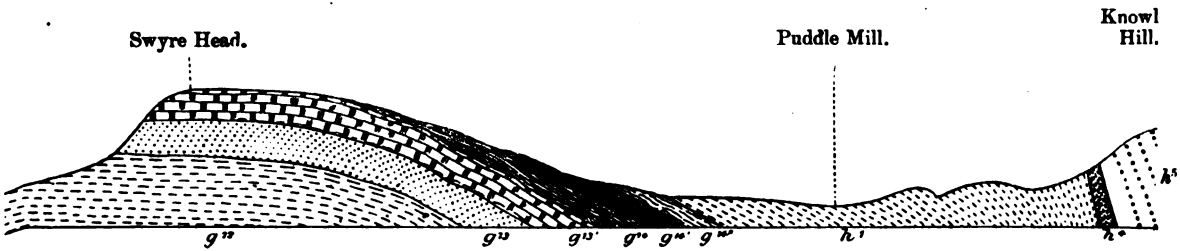



Fig. 83. Section across the Isle of Purbeck (distance 2½ miles).

$h^5$. Chalk. $h^4$. Upper Greensand. $h^1$. Wealden Beds.
$g^{14}$. Purbeck Beds. $g^{13}$. Portland Stone and Sand. $g^{12}$. Kimeridge Clay.

### 2. *Central District.*

In this part of England a broad mass of clay intervenes between the outcrop of the Cornbrash and the base of the Cretaceous series. In Bucks, Beds, and Huntingdon the greater part of this is referable to the Oxford clay, but in Cambridge and Lincoln the Kimeridge clay also occupies a considerable area. The Corallian is either entirely absent or feebly developed.

**Oxford Clay.**—Little is known regarding this clay in Bucks or Beds, but in Huntingdon Professor Judd[1] distinguishes the following zonal divisions:—

6. Clays with *Ammonites* of the *Cordatus* group.
5. „ „ *Ornatus* group.
4. „ *Belemnites hastatus.*
3. „ „ *Owenii.*
2. Shales, with *Nucula nuda.*
1. Sandy clays and sands with *Gryphæa bilobata* = Kellaways Beds.

The whole is probably from 500 to 600 feet thick, and in the upper part of Zone 6 there are several beds of calcareous sandstone, the thickest of which is known as the St. Ives rock; this contains *Am. cordatus* and *Am. Bakeriæ*, while the enclosing clays contain *Am. Lamberti* and *Am. Mariæ* in abundance.

The Oxford clay borders and underlies the western part of the Fen district, emerging on the north side of the Witham, near Bardney, and passing northward to the valley of the Ancholme, and across the Humber into South Yorkshire.

**Corallian Group.**—This division is believed to be represented by clays, with bands of limestone, near Ampthill, but these do not contain a Corallian fauna, only a mixture of Oxford and Kimeridge clay species.

Near Elsworth and Papworth (West Cambridgeshire) there are two bands of hard ferruginous limestone, which are believed to represent the Lower and Upper Calcareous

[1] "Geology of Rutland, Mem. Geol. Survey," p. 232.

Grits, separated by clay, without any trace of Coral Rag. The lower or Elsworth rock was first studied by Professor H. G. Seeley; it contains many fossils, among which are *Ammonites Henrici, A. cordatus, A. perarmatus, Phasianella elegans,* and *Gryphæa dilatata.*

At Upware, between Cambridge and Ely, there is an isolated mass of undoubted Coral Rag, which seems to be part of a true coral-reef; one pit exposes coral limestone, with *Thamnastrea arachnoides* and *Isastrea explanata, Cidaris florigemma, Opis, Plicatula, Lithodomus,* and other inhabitants of the reef; while another pit is opened in soft yellowish oolite, without corals, but containing *Echinobrissus scutatus* and *Holectypus depressus.*

In Lincolnshire there is nothing to represent the Corallian group, the Oxford clay merging gradually into the Kimeridge, without even anything resembling the Supracoralline beds, these being only developed in presence of the Coral Rag.

**Kimeridge Clay.**—Between Aylesbury and Leighton the greater part of this clay is concealed by the Gault, and beyond Leighton by the Woburn sands, no Kimeridge being coloured on the map of the Geological Survey till we reach the neighbourhood of Papworth, where it comes in above the Calcareous Grits, and runs in a narrow belt by Knapwell, Boxworth, and Cottenham to the Fens. It is seen again in the Isle of Ely, where beds with *Ammonites serratus, Exogyra virgula,* and reptilian bones (Lower Kimeridge) are succeeded by shales with *Discina latissima* and *Lucina minuscula* (Upper Kimeridge), though only a small thickness of the latter is exposed.

In Lincolnshire both the lower and upper stages are well developed,[1] the lower being some 400 feet thick, and consisting of clays with large septaria, containing *Am. serratus, Am. decipiens,* &c., with *Astarte supracorallina;* the upper beds are shales, with bands of limestone and the usual fossils, perhaps 300 feet thick. The whole formation is gradually overstepped by Cretaceous rocks, and disappears north of Brigg.

**Portland Beds.**—The most northern outlier of these

[1] See J. F. Blake, "Quart. Journ. Geol. Soc.," vol. xxxi. p. 196

beds is at Stewkley Warren, four miles west of Leighton Buzzard; the Portland stone capped by the freshwater (? Purbeck) beds, like those of Hartwell, being here exposed. Beyond this they are never seen again, but derived fossils of Portlandian species occur frequently in the Cretaceous nodule beds, and consequently it seems probable that the Portland rocks once extended much farther north.

### 3. *Northern District.*

In the north of Yorkshire representatives of all the Upper Jurassic groups come in again, with the exception of the Purbecks, and are well exposed along the coast near Scarborough.

**Oxford Clay.**—Succeeding the Cornbrash are 10 or 12 feet of shale, with *Avicula echinata*, which are grouped with the Cornbrash by Hudleston, and with the Kellaways by Etheridge. The Kellaways rock as seen in Gristhorpe Bay is only 5 feet thick, and is succeeded by the shales of the Oxford clay, but at Scarborough, five miles to the north-west, there are no less than 80 feet of sandstone below this clay. It seems, however, that only the lower 30 feet of this belong properly to the Kellaways, for the higher beds contain *Belemnites Owenii*, *Gryphæa dilatata*, and Ammonites of the *Ornati* group, which characterize the lower part of the Oxford clay elsewhere. Above this sandy zone are grey sandy shales from 120 to 150 feet thick, containing *Am. Lamberti*, *Am. cordatus*, *Am. crenatus*, and other fossils. Westward both shales and sands decrease in thickness, and are only 80 feet thick in the Howardian Hills.

**Corallian Group.**—This attains an unusual thickness in Yorkshire and occupies a large area of ground round the Vale of Pickering. It has been specially studied by Messrs. Blake and Hudleston, from whose paper[1] the following tabular view of the succession near Pickering has been prepared:—

[1] "Quart. Journ. Geol. Soc.," vol. xxxiii. p. 260.

| | |
|---|---|
| Upper Division, in three stages, 95 feet. | Coral Rag, with *Am. varicostatus*, *Cidaris florigemma*, *Hemicidaris intermedia*. |
| | *Coralline oolite*, compact and oolitic limestones, with *Chemnitza Heddingtonensis*, *Trigonia Meriani*, and *T. perlata*. |
| | Middle Calcareous Grit, with *Am. plicatilis*. |
| Middle Division, in two stages, 90 feet. | Small-grained oolitic limestones, with *Am. perarmatus* and *Am. cordatus*. |
| | Coarse gritty and cherty limestones, with *Am. goliathus*, *Waldheimia bucculenta*, and *Rhynchonella Thurmanni*. |
| Lower Division, 100 feet. | Lower Calcareous Grit, consisting of hard grey gritty limestones and soft yellowish calcareous sand-rock, *Am. cordatus*, *Gervilia aviculoides*, *Rhync. Thurmanni*. |

The total thickness here, therefore, is 285 feet, with 20 feet of shales and Grit above, which have usually been called Upper Calcareous Grit, but which are classed as Supra-coralline beds by Hudleston and Blake.

On the coast the series is thinner, not more than 200 feet (Lower Calcareous Grit 80 feet, greystones and limestones 80 feet, middle grits and upper limestones 40 feet).

**Kimeridge Clay.**—This occupies the low ground in the Vale of Pickering, but is covered by drift deposits, and is only exposed at a few points along the coast of Filey Bay. The Supra-coralline beds near Pickering are 20 feet thick, consisting of earthy limestones and shales (13 feet) with reddish calcareous grit above (7 feet); the fossils are *Am. alternans*, *Am. varicostatus*, *Belemnites nitidus*, *Thracia depressa*, and others. The mass of dark Kimeridge clay to the eastward is supposed to be more than 500 feet thick. Professor Judd[1] distinguishes three divisions: a lower with *Am. alternans* and *Rhync. inconstans*, a middle with *Exogyra virgula*, and an upper set of black bituminous shales with *Discina latissima* and *Lingula ovalis*.

**Portland Beds.**—At the top of the Kimeridge clay at Speeton there are certain dark clays with stony bands containing *Am. gigas*, *Am. Gravesianus*, *Am. rotundus*, and *Lucina Portlandica*, overlain by peaty clay with fish remains. These are regarded by Professor Judd as Portlandian. They are succeeded by a bed of phosphatic nodules, in which the same fossils occur as water-worn pebbles, and which forms the base of the overlying Neocomian clays.

[1] "Quart. Journ. Geol. Soc.," vol. xxiv. p. 238.

### 4. *Scotland.*

**West Coast.**—The only member of the Upper Jurassic series which is found on the west coast of Scotland is the Oxford clay. This overlies the great estuarine series in the islands of Skye and Eigg, and consist of blue clays containing *Ammonites cordatus, Am. excavatus, Am. Lamberti,* and others. Above it are Cretaceous rocks.

**East Coast.**—In Sutherland a much more complete series is found; they are seen at intervals along the coast for a distance of sixteen miles, and form a narrow strip of low ground, which is bounded inland by a powerful fault, and the extreme width of which near Brora is about two miles.[1] In this small space is found a succession of beds representing the whole of the Oxford clay, Coral Rag, and part of the Kimeridge clay, as below:—

| | | Feet. |
|---|---|---|
| Kimeridge Clay. | Light-coloured sandstone, no fossils | 100 |
| | Shelly limestones, black shales, and grits, with *Bel. abbreviatus, Am. alternans, Am. biplex,* and many others; Ferns, Cycads, and Conifers | 500 |
| | White sandstones and carbonaceous shales; estuarine beds, with few fossils | 200 |
| | Grits and sandstones; *Am. biplex, Am. eudoxus, Am. mutabilis,* and *Bel. obeliscus* | ? 200 |
| Corallian. | Grey limestones and sandy clays in two bands, separated by 60 feet of white sandstone; *Am. cordatus, Am. excavatus, Trigonia corallina,* and other Coral Rag species | ? 150 |
| | White sandstones, with bands of lignite, and occasional layers containing casts of marine shells; estuarine beds | 400 |
| | White cherty sandstone, with many fossils, *Am. peramatus, Am. achilles,* &c. (Lower Calc. grit) | 25 |
| Oxford Clay. | Sandy clays and black shales, with *Bel. Owenii, Bel. hastatus, Am. ornatus, Am. Duncani,* &c., &c. | 300 |
| | Sandy shales, with *Nucula nuda, Am. Goweriamus,* and *Am. Calloviensis* | 5 |
| | Calcareous sandstone with many fossils, fauna of Kellaways rock | 5 |

It will be useful to indicate here the conditions under which these three groups were deposited.

[1] J. W. Judd, "Quart. Journ. Geol. Soc.," vol. xxix. p. 164 *et seq.*

1. Oxford clay—entirely marine.
2. Corallian—chiefly estuarine.
3. Kimeridge clay—partly estuarine, partly marine, but in close proximity to land.

Further north, near the Ord of Caithness, thick beds of breccia alternate with the shales of the Kimeridge clay, and testify to the frequency of floods and the torrential action of the streams which emptied themselves into the bay (see p. 365).

## Physical Geography and Formation of the Rocks.

**1. Lower Jurassic Time.**—The physical geography of the Rhætic and Liassic epochs was a simple and direct modification of that which prevailed during the preceding Triassic period. No local elevations and subsidences took place in the British area, for the Rhætic and Liassic beds occupy the same basins of deposit as those which hold the Keuper marls; the great lakes or inland seas in which the latter were accumulated became by submergence the seas and bays in which the shales and limestones of the Lias were laid down.

This submergence set in doubtless toward the end of the Triassic period, and affected the whole of the Triassic north-European continent; the epoch of the *Avicula contorta* zone marks the time when the depression had proceeded so far as to submerge the lowest tract of land which lay between the great salt lakes and the wide-spreading southern ocean. It is very probable that at this time the level of the water in the salt lakes had been greatly reduced by evaporation, and was perhaps several hundred feet below that of the sea outside, and that when the dividing barrier was submerged, the sea waters would rapidly invade the lake basins and fill them up to a common level.

Let us consider the nearly parallel case of the Caspian Sea at the present day; the level of this sea is 85 feet below that of the Black Sea, and it is surrounded by extensive low-lying areas which were formerly covered by its waters before the sea shrank to its present dimensions; if

therefore the waters of the Black Sea were admitted to the Caspian through the depression of the present barriers, they would quickly spread over a large area in Central Asia which is now for the most part a dry and sandy desert. I do not mean to infer that anything like a cataclysmal influx of water would take place; the first inroad would doubtless occur during the prevalence of a strong west wind,[1] and would be only a temporary invasion, but as submergence went on, such invasions would be of frequent occurrence, till at length a permanent connection was established.

Two important results would follow from such a change: (1) large numbers of the creatures living in the Caspian would be immediately killed unless they could support the changed conditions of water and food; if destroyed, their remains would doubtless be laid out, and stratified, as it were, on the bottom of the sea, thus forming *bone-beds*. (2) the climate and appearance of the surrounding country would be gradually altered; evaporation from the newly-created sea would give rise to the formation of clouds; these would fall again as rain on the neighbouring hills; rills and rivers would come into existence, and the ordinary processes would be set in action; the country would be irrigated and fertilized, and the products of erosion would be washed into the widening sea. A scene of death and decay, desert wastes and slowly shrinking lakes would be converted into a sea full of active creatures, bordered by a region where the plash of waters and the hum of insects were unceasing sounds.

Such must have been the change which ensued when the Rhætic waters filled the basins of the Triassic lakes. The bone-beds testify to the suddenness of the invasion and the inability of the Triassic fish and reptiles to survive the change. The absence of Cephalopoda from the Rhætic beds shows that at first the waters were shallow, these creatures requiring the vicinity of an open sea and deep water; their presence, therefore, in the very lowest beds of the Lias indicates that these conditions were rapidly attained. The plants and insects found both in Rhætic and Lias testify to the altera-

[1] If there were tides in the Black Sea, it would occur when there was an unusually high tide.

tion of the climate, the humidity of the air, and the general fertility of the surrounding region; while the enormous abundance of fossils in the Lias proves that life had multiplied exceedingly, and that the Liassic sea must have presented a great contrast to the heavy and nearly lifeless waters of the Triassic lakes.

The geography of the British area, so far as concerned the relative positions of land and water, was similar to that of the Triassic period. Sea covered all the central and southern part of England; but there was a larger area of land to the east of our islands, and a portion of this extended into the east of England,[1] though the trend of its coast is quite uncertain. About the land on the west we have more information; it was probably continuous from the north of France through Cornwall, Devon, Wales, and Ireland; the sites of the English, Bristol, and Irish Channels seem to have been bays or gulfs running up into this land; and these channels then narrowed westward, opening into an eastern, and not a western sea as they do now; as to the Irish Channel we have no certain information, but if a gulf then existed on its site it doubtless opened northward and narrowed southward.

The Mendip Hills formed an island at the mouth of the gulf that separated Devon and Wales, and the northern shore of this gulf ran through Glamorgan, Monmouth, and Gloucester, to the Malvern Hills; thence the coast trended north-westward along a line which lay to the west of the present boundary of the Trias; from Denbigh it passed across the Irish Sea into the north-east of Ireland, and thence northward to the west coast of Scotland.

Nearly the whole of Scotland and the north-west of England seems to have been land which projected southward in a long promontory as far as Derbyshire, thus dividing the sea-space into two large irregular gulfs, one stretching across the Irish Sea and along the western coast of Scotland as far as Skye and Raasey, the other spreading round the eastern side of Scotland, and only touching modern Scottish soil again in Elgin and Sutherland. How far this eastern sea extended northward beyond the latitude of our islands we

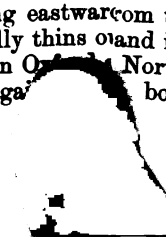
[1] This is proved by the absence of the Lias under the London Basin, where the Great Oolite is the only representative of the Jurassic system.

have no means of knowing, but it probably occupied a large part of what is now the North Sea, and was bounded by a southerly projection of the Scandinavian peninsula.

The deposition of so great a thickness of dark-coloured clay and shale in Liassic times calls for explanation, and it may be fairly assumed that this material was mainly supplied by the destruction of the Carboniferous shales. Large tracts of coal-measures and of Lower Carboniferous shales must have existed at this time both in Ireland and Scotland, and the rivers flowing off these tracts would pour little else than black mud into the surrounding sea, while the waves would eat deep into such portions as came within their reach during the gradual submergence.

2. **Middle Jurassic Time.**—The physical geography of the British Islands during this part of the Jurassic period does not seem to have differed much from that which prevailed during Liassic times. The same general arrangement of sea and land which has just been described, continued during the formation of the Oolites, though certain important changes and modifications of the coast-line seem to have taken place, otherwise it would be difficult to explain the complete change in the character of the sediment laid down—the change from the dark shales of the Lias to the sands, marls, and oolitic limestones of the newer series. At first sight nothing seems easier to explain than such a change; a clay succeeded by a limestone seems to point to a general depression, whereby the extent of the sea was enlarged, and its depth increased; but it is an error to suppose that all limestones are deep-water formations (see Physical Geology, Part I., ch. xii.), and oolitic limestones in particular are generally of shallow-water origin. Again, if the Coal-measures were, as above suggested, the source of the mud composing the Lias, the supply of this might be cut off by elevation as completely as by submergence. Finally, in the Midland counties of England we have distinct evidence of the close proximity of land throughout the Middle Jurassic period.

We have seen that in passing eastward from the Cotteswolds the Inferior Oolite rapidly thins out and is partially represented by estuarine beds in Oxfordshire and Northampton; marine limestones come in again both to the



north-east in Rutland, and to the north-west in North Oxfordshire. These facts point to the existence of land in the east of England, which, however, was partially submerged during the epoch of the Great Oolite, for beds of that age occur beneath London. Again, in Yorkshire and on both sides of Scotland we find freshwater and estuarine conditions prevailing more or less throughout the whole of the Inferior and Great Oolite epochs. All the evidence, therefore, tends to the conclusion that the change from Lias to Oolites was caused by upheaval, and that the latter were deposited in a shallower sea than the former.

We are then justified in picturing that portion of the Middle Jurassic sea which lay over the Midland counties of England as a comparatively narrow belt, less than 100 miles wide, and bounded on the one hand by the mountainous region of Wales and on the other by the land of Palæozoic rocks which now lies below the eastern counties. Southward this belt probably opened into a wider sea, through which came currents of warm water from equatorial regions, imparting a high temperature to the British shores, and enabling reef-building corals to flourish where other conditions were favourable to their existence. Northward the sea probably divided into two arms as in Liassic times, one passing up the west coast, and the other outside the east coast of Scotland.

In this sea flourished an immense number of marine creatures, the number of species found in Britain alone being over 1,700; coral-reefs were formed from time to time, and their *débris* afforded the material for the oolitic limestones which now furnish such valuable building stones. On the surrounding land grew magnificent Ferns and Cycads, with Coniferous trees on the higher ground; but so far as we know the only vertebrate denizens of the region were small Marsupials, huge Dinosaurian Reptiles, and the bat-like Pterodactyles.

The country which now exhibits the nearest approach to such a scene as Britain must then have displayed is Australia and its neighbouring islands. There many of the Jurassic types still survive. The indigenous Mammalia are all Marsupials; the plants include Ferns, Cycads, and Araucarian pines. Coral-reefs fringe the shore, and in the

waters are Cestraciont Fish, and many of the same Molluscan genera as are found in the Oolites, viz., *Phasianella, Stomatia, Trigonia, Corbis,* and *Terebratula,* with others that have a wider distribution. There are, however, no survivors of the Jurassic Reptiles, nor of the Ammonites and Belemnites which swarmed in the older seas.

The varying characters of the Middle Jurassic strata testify that the period was one of many phases; there is, indeed, as pointed out by Professor Phillips,[1] a striking parallelism in the order which the arenaceous, calcareous, and argillaceous deposits of this series exhibit in the southern counties; thus the beds may be arranged in ternary groups as below:—

| | |
|---|---|
| Calcareous. | Cornbrash and Forest Marble. |
| Argillaceous. | Bradford Clay. |
| Calcareous. | Great Oolite. |
| Arenaceous. | Stonesfield Slate. |
| Argillaceous. | Fuller's Earth. |
| Calcareous. | Inferior Oolite. |
| Arenaceous. | Midford Sands. |

The arenaceous beds, then, may be regarded as indicating epochs of elevation, during which the shallower parts of the sea were silted up with littoral and estuarine deposits. The calcareous beds prove temporary depression and recession of the coast-lines, but not necessarily a deep sea, only clear water, and conditions favourable to the growth of coral-reefs. The argillaceous marls may have been formed in rather deeper water than the limestones, or they may only indicate the influx of mud-bearing currents which prevented the growth of coral-reefs.

The various surfaces of erosion which have been observed (*vide* pp. 327 and 329) prove that the sea-bottom was often brought within the influence of powerful currents, that the limestones of the Inferior Oolite had originally a far wider and more continuous extension than they have now, but that large portions of them were broken up and destroyed by contemporaneous erosion. It follows, therefore, that the

[1] "Geology of Oxford," p. 393.

strata we are acquainted with are by no means all that were formed over the British area during this period of time; nevertheless, as the gaps in one district seem to be partially filled up by deposits in another, we obtain a fairly complete record of the succession of life-forms in the British province.

3. **Upper Jurassic Time.**—From the stratigraphical facts recorded in the foregoing pages we may draw two conclusions with regard to the physical conditions under which the Upper Jurassic rocks were deposited. The first inference is that the sea of the Oxford and Kimeridge clays was much deeper and more extensive than the reef-blocked seas of the Middle Jurassic times. Secondly, we infer that this sea again became shallower, partly by deposition, and partly by upheaval, during the Portland and Purbeck times, till eventually the greater portion of it was raised into dry land.

If further testimony to the shallowness of the Great Oolite waters were needed, the scarcity of Ammonites in the rocks of that group would supply it, only three species being known to occur in the Forest Marble and Cornbrash. The sandy nature of the Kellaways rock precludes us from supposing it to have been a deep-water deposit, but its fauna indicates that deep water was not far off, for in these beds a large number of new Ammonites suddenly make their appearance, and most of them continue in the Oxford clay. The change from Cornbrash to Kellaways Rock is particularly striking in Yorkshire, where the latter contains no fewer than forty-one species of Ammonites, and only one is common to the two deposits; twenty of these species pass up into the Oxford clay. Mr. Hudleston, who has made such a careful study of the Yorkshire Oolites, remarks:[1]—"Probably this great sandbank was deposited during a submergence of this region far more continuous in time and extended in space than those more partial depressions which during the period of the Lower Oolites (Middle Jurassic) had in this region intercalated the spoils of the sea with those of the estuary and the marsh. This more continuous descent seems at length to have removed or lowered

[1] "Proc. Geol. Assoc.," 1875.

barriers which had hitherto kept out the waters of a sea swarming with strange Cephalopoda."

One of these barriers was undoubtedly that ridge or promontory which stretched from Belgium into the eastern part of the British area throughout the Liassic and Middle Jurassic periods. The southern part of this ridge began to be submerged during the formation of the Great Oolite which rests on the Trias beneath London, and though the Oxford clay is not there found, it occurs below Chatham, and its absence further north is doubtless due to the great denudation which took place in Cretaceous times (see fig. 91, p. 379, and fig. 53, p. 276).

We may therefore assume that this promontory was completely submerged during the formation of the Oxford clay, and that by the close of this epoch a continuous deposit of the clay was spread over the whole of the eastern and midland portion of the British area, and that even the Scottish coast-lines were carried back so far that the same clay was spread over areas where only estuarine deposits had previously been laid down (see pp. 333 and 356). In this great deposit of dark blue clay we seem to have a repetition of Liassic conditions, and it is highly probable that the source of supply was the same—namely, the Coal-measures which once covered so large a portion of Wales, Ireland, and North Britain.

After a time the distribution of the dark mud became less universal, and in places where the water was shallower, and from which the muddy currents were excluded, a few coral-reefs were formed, with their accompaniments of calcareous sands, marls, and limestones (Corallian beds); a further submergence, however, overwhelmed these spaces, and spread out another great and continuous deposit of mud (the Kimeridge clay), which was doubtless as far-reaching as that of the Oxford clay.

Eventually, however, a reverse movement set in, the supply of mud grew scantier, and the bluish argillaceous sands which underlie the Portland stone were doubtless formed during upheaval; the sea became clearer and shallower, and the formation of limestone was once more possible. Finally, a large part of the sea-bottom was raised into dry land, the sea was contracted into far narrower

limits, and over southern England was reduced to an estuarine lagoon, in which the Purbeck beds were accumulated.

It is important to remember that this elevation must have again upraised the ridge of Palæozoic rocks which underlies the east of England, and it was doubtless the connection of this ridge with the southern end of the Pennine chain which caused the limitation of the Purbeck beds to the Purbeck-Wealden basin. With this in view there is nothing to surprise us in the occurrence of an estuarine (or Purbeck) episode in Upper Portland times on the southern side of this ridge in Bucks and Oxford.

Lastly, let us glance for a moment at the north-eastern shore of Scotland, which was indented then as now by the deep bay of the Moray Firth, though its southern shore stretched much further eastward. Here, as we have seen (p. 357), deposition was in progress throughout the Upper Jurassic times, but the frequent recurrence of estuarine beds shows that parts of the bay were silted up from time to time by the immense quantity of sand which was poured into it by the rivers from the neighbouring hills.

The brecciated beds in the Kimeridge clay of the Ord also tell a story which is thus deciphered by Professor Judd,[1]—"The alternation of the brecciated beds with the finely laminated and quietly deposited strata and the confused arrangement of the blocks in the former, their admixture with trunks of trees, stems of cycads, and other plant remains, seem to indicate that the quiet deposition of the semi-estuarine beds was interrupted by the occasional occurrence, in the rivers just alluded to, of floods of the most violent character. These appear to have swept angular masses, just separated from their parent rock by frosts or landslips, subangular masses which had lain for a time in the course of the streams, and the rounded pebbles of the river-beds, along with trunks of trees torn from their banks, all in wild confusion out to sea, where they were mingled with the sea-derived materials of the shell-banks and shoals."

[1] "Quart. Journ. Geol. Soc.," vol. xxix. p. 195.

## CHAPTER X.

### THE CRETACEOUS SYSTEM.

EXCEPT in the south of England there is everywhere a marked break and unconformity between the Jurassic and Cretaceous systems, but where the highest Jurassic beds are fully developed, as in Dorsetshire, there we find a complete sequence of deposits through the freshwater Purbeck and Wealden groups, which fills up the gap that elsewhere exists between the two systems. It is clear, therefore, that this gap was caused by the elevation of the British area into dry land, the southern part of which was traversed by a great river. The Wealden beds are usually taken as the base of the Cretaceous system, but some classificators protest against the separation of the Purbeck and Wealden, and would either group them together as a transition series or place them both in the Cretaceous system. I prefer, however, to adopt the usual grouping for reasons already given.

The system is divisible into two great series, a lower and an upper, and the following table shows the subdivisions which have been adopted for the rocks of the southern counties; this nomenclature, however, is not applicable to the lower series in Lincolnshire and Yorkshire.

| | | Max. thickness. Feet. |
|---|---|---|
| Upper Cretaceous. | Upper Chalk (Senonian) . . . | 600 |
| | Middle Chalk (Turonian) . . . | 250 |
| | Lower Chalk (Cenomanian) . . | 200 |
| | Upper Greensand and Gault . . | 250 |
| Lower Cretaceous. | Lower Greensand (Vectian) . . | 800 |
| | Weald Clay, Hastings Sand } Wealden . . | 2,000 |
| | | 4,100 |

As, however, a large part of our Lower Cretaceous is of freshwater origin, and the summit of the Chalk is nowhere visible, it is desirable to furnish the student with a table of the Continental equivalents which supply us with a complete succession of marine Cretaceous rocks; these are as follows, with their maximum thicknesses:—

| | | Feet. |
|---|---|---|
| Upper. | Danien, or Maestricht Chalk | 100 |
| | Senonien | 600 |
| | Turonien | 500 |
| | Cenomanien | 300 |
| | Albien | 300 |
| Lower. | Aptien, Rhodanien | 600 |
| | Urgonien | 1,000 |
| | Neocomien | 3,000 |

The Aptien and Rhodanien represent our Lower Greensand, the Urgonien and Neocomien are the marine equivalents of the Wealden.

## Range and Relation to Rocks below.

Cretaceous rocks underlie the whole of the south-eastern part of England; their main outcrops form a broad tract which runs across the country from Dorsetshire to the west of Norfolk, and if the south-easterly dip was maintained without interruption they would pass beneath the Tertiary deposits which succeed the Chalk; but this dip is interrupted by several large cross-flexures, the axes of which run in an east and west direction, and by these flexures the Cretaceous rocks are brought to the surface over a large area in the south of England, while the Tertiary rocks are thrown off into two synclinal troughs or basins.

There are three principal anticlinal axes: one running through Dorset and the Isle of Wight; a second running through the Vale of Wardour, Winchester, and the north of Sussex (see fig. 82); a third running through the Vale of Pewsey and Kingsclere. It is by the second of these flexures that the Lower Cretaceous rocks have been brought up in

the Wealden area of Kent and Sussex, the structure of which is illustrated on pp. 378 and 379.

North of the Thames Valley there are no such disturbances; the easterly dip is uninterrupted and the great escarpment of the Chalk is continuous through the counties of Oxford, Bucks, Beds, Herts, Cambridge, and Norfolk, till it sinks beneath the waters of the Wash. In Norfolk the strike is nearly due north and south, but this is changed beneath the Wash, and the rocks emerge in Lincolnshire with a strike to N.N.W., crossing the Humber west of Hull, and forming the districts known as the Lincolnshire and Yorkshire Wolds.

In Ireland Upper Cretaceous rocks crop out in many places beneath the Basalt plateau of Antrim and Londonderry, the whole of which they doubtless underlie.

Upper Cretaceous rocks are also found in the west of Scotland, but though the exposures are very interesting in themselves, the areas occupied by them are very small.

The relation of the Cretaceous rocks to the underlying strata is an important subject of consideration. It has been stated that where the Wealden beds are present they rest with perfect conformity on the Purbeck below, but in the west of Dorset the upper members of the Cretaceous system rapidly overlap the lower, and at the same time overstep the members of the Jurassic series below, till at length the Upper Greensand comes to rest upon the Lias, and outliers of it occur even on the Trias of Devonshire.

A similar overlap and overstep takes place in the Midland counties, the Lower Cretaceous Beds being overlapped by the Gault, which passes across the edges of the Purbeck and Portland beds till, in Bucks, it rests upon the Kimeridge clay. These facts demonstrate that the sea of the Upper Cretaceous period had a far wider extension than that of the Lower Cretaceous. As this sea encroached upon the land which lay to the north of the Wealden area in Lower Cretaceous times, it planed off a considerable thickness of strata, and the surface upon which the Upper Cretaceous rocks now rest in the east of England is a plane of marine erosion (see fig. 53). Borings at Richmond and at Meux's Brewery in Tottenham Court Road pass from

Gault into Great Oolite, with a doubtful representative of the Lower Greensand in the former case; a boring at Kentish Town passed from Gault into red sandstones supposed to be Trias, while borings in Essex came down upon Palæozoic rocks of Silurian and Devonian age. The following are abstracts of some of these borings:—

| | Richmond. | Meux's Brewery. | Kentish Town. | Cheshunt. | Ware. |
|---|---|---|---|---|---|
| Gravel and Drift | 11 | 22 | — | 20 | 14 |
| Eocene | 242 | 136½ | 324½ | 50 | — |
| Chalk | 871 | 655½ | 645 | 730 | 601? |
| Upper Greensand | 16 | 28 | 13½ | 20 | 20 |
| Gault | 201½ | 160 | 130½ | 161 | 161 |
| Lower Greensand? | 10 | — | — | — | — |
| Great Oolite | 87½ | 64 | — | — | — |
| Trias? | 170 | — | 188½ | — | — |
| Devonian | — | 80 | — | 30 | — |
| Silurian | — | — | — | — | 43 |
| | 1409 | 1146 | 1302 | 1011 | 839 |

## Life of the Period.

The Cretaceous forms of life, especially those of the marine Neocomian and Lower Greensand, are clearly the modified successors of the Jurassic species; and the general aspect of the Cretaceous fauna resembles that of the preceding Jurassic, more than it does that of the succeeding Eocene or Hantonian system. Throughout the Lower Cretaceous (marine) series we find many genera which were abundant in Jurassic times still represented, such as *Astarte*, *Cucullæa*, *Trigonia*, *Corbis*, *Gervillia*, *Myacites*, *Perna*; with the Echinoderms *Echinobrissus*, *Holectypus*, and *Pygurus*. *Ammonites* and *Belemnites* were as abundant in Cretaceous as they were in Jurassic times; the great Jurassic reptiles *Ichthyosaurus*, *Plesiosaurus*, *Ceteosaurus*, and *Megalosaurus* are by no means uncommon in Cretaceous rocks.

During Upper Cretaceous time, however, great changes took place; the whole British area became part of a deep sea, and the shallow-water, littoral, and terrestrial types which flourished in the earlier portion of the period were forced to migrate to other shores, and the more inflexible types, which could not change with the changing conditions,

died out altogether and became extinct. There can be little doubt that it was the constantly increasing extent and depth of the Cretaceous sea or ocean which caused the extinction of so many Mesozoic forms in the European area.

The following are the principal genera which came into existence during the Cretaceous period:—

*Spongida.*—Brachiolites, Cephalites, Siphonia, Ventriculites, Pharetrospongia, Plocoscyphia, Stauronema.

*Actinozoa.*—Caryophyllia, Cyathina, Holocystis, Micrabacia, Parasmilia, Smilotrochus.

*Echinodermata.*—Ananchytes (Echinocorys), Cardiaster, Cyphosoma, Discoidea, Galerites (Echinoconus), Hemiaster, Hemipneustes (Toxaster), Holaster, Micraster, Salenia, Peltastes, Marsupites.

*Crustacea.*—Enoploclytia, Hoploparia, Meyeria, Necrocarcinus, Palæocorystes.

*Brachiopoda.*—Magas, Terebrerostra, Trigonosemus.

*Lamellibranchiata.*—Caprina, Caprotina, Diceras, Hippurites, Radiolites (all belonging to one abnormal family).

*Gasteropoda.*—Aporrhais (Ornithopus, Dimorphosoma), Avellana (Cinulia), Crepidula, Rostellaria?

*Cephalopoda.*—Baculites, Hamites, Crioceras, Scaphites, Turrilites, Belemnitella.

*Pisces.*—Lamna, Otodus, Notidanus, Edaphodon, Beryx, Ptychodus, Saurocephalus, Microdon.

*Reptilia.*—Acanthopholis, Iguanodon, Polyptychodon, Mosasaurus.

## STRATIGRAPHY.

### § A. Lower Cretaceous Series.

The English strata belonging to this series come to the surface in four different areas or districts, and may, therefore, be described conveniently in four sections, though doubtless these areas are all connected beneath the overlying rocks to the eastward. These are (1) the Wealden or South-eastern; (2) the South-western, including the Isle of Wight; (3) the Midland; (4) the Northern. In the first two there is a complete succession of beds, but the greater

part of them are of freshwater origin, only the upper portion being marine; in the Midland area only a part of these upper marine beds are found; in Yorkshire we have a more perfect series of marine deposits, but they do not attain any great thickness, and were formed in a sea which had little or no connection with that of the southern areas. This northern district will not, therefore, serve as a type to which such marine beds as occur in the south could be referred; for the true equivalents of the latter we must go to France, and some account of the French deposits will be given later on. The characteristic fossils of the two French divisions, which do not occur in England, are given below, but for the upper members of the series British species are given, though many of these also occur in the corresponding French strata (Rhodanien and Aptien).

## Fossils of the Neocomien.

*Echinodermata.*—Toxaster complanatus, Pygurus rostratus, Echinobrissus Olfersi, Pseudodiadema rotulare.

*Brachiopoda.*—Terebratula diphyoides, Rhynchonella multiformis.

*Lamellibranchiata.*—Ostrea Couloni, Cardium peregrinum, Diceras Germaini.

*Gasteropoda.*—Tornatella albensis, Natica Hugardiana, Nerinæa Marcousana.

*Cephalopoda.*—Belemnites lateralis, Ammonites Astierianus, Am. neocomiensis, Am. radiatus, Am. Rouyanus.

## Fossils of the Urgonien.

*Echinodermata.*—Heteraster Couloni, Pygurus productus, Hemicidaris clunifera.

*Brachiopoda.*—Rhynchonella lata.

*Lamellibranchiata.*—Requienia ammonia, Pecten robinaldinus, Janira atava.

*Gasteropoda.*—Nerinæa Renauxiana, Trochus crucianus.

*Cephalopoda.*—Ammonites Perezianus, Ancyloceras Ennerici.

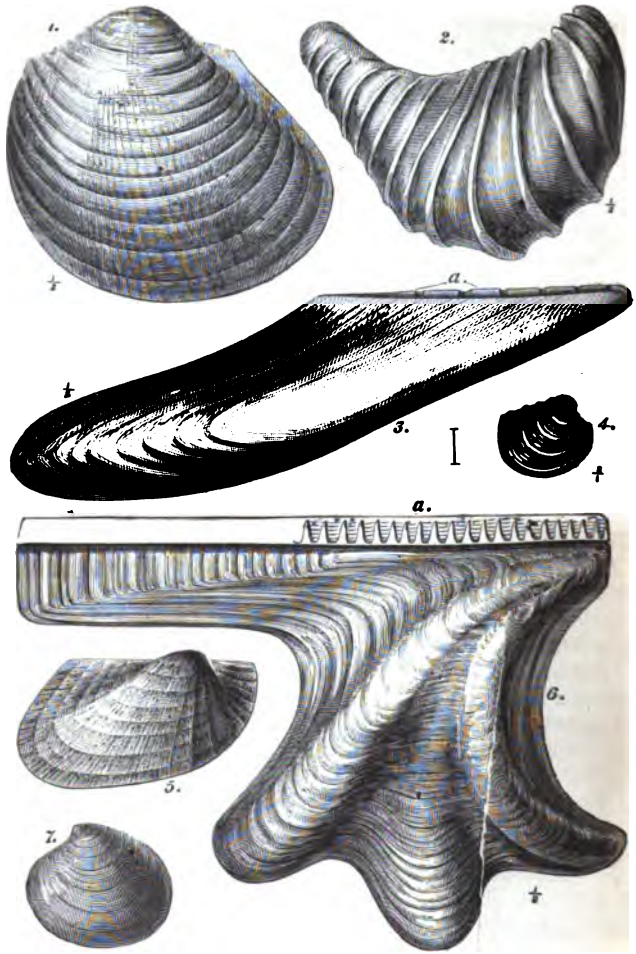



Fig. 84. Lower Greensand Fossils.

1. Corbis corrugata.
2. Trigonia caudata.
3. Gervillia anceps.
4. Venus striato-costata.
5. Arca Raulini.
6. PernaMulleti.
7. Venu parva.

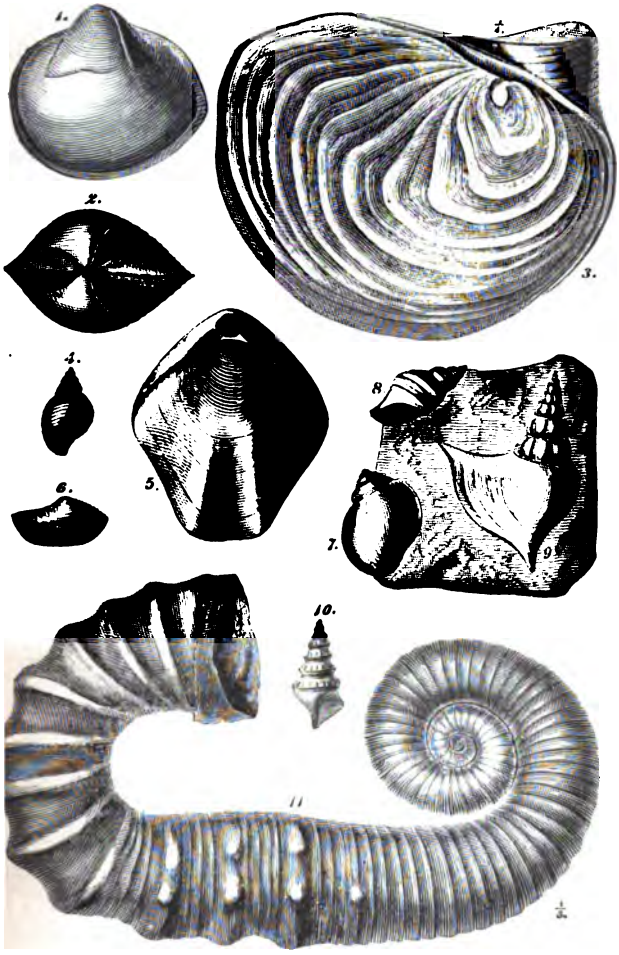


Fig. 85. Lower Greensand Fossils.

1, 2. Thetis minor.
3. Exogyra sinuata.
4. Tornatella albensis.
5. Terebratula sella.
6. Leda scapha.
7. Natica rotundata.
8. Ornithopus Fittoni (young).
9. Aporrhais robinaldina.
10. Cerithium turriculatum.
11. Ancyloceras gigas.

Perna Mulleti, Gervillia aus
caudata, T. dædalea, Corbis corr
*Gasteropoda.* — Tornatella all
Aporrhais robinaldina, Ornithopt
*Cephalopoda.*—Ammonites furc

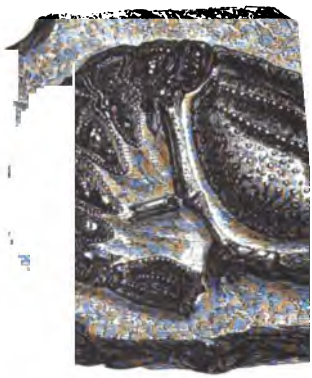


Fig. 86. Meyeria v

## Fossils of the Hythe Beds, (

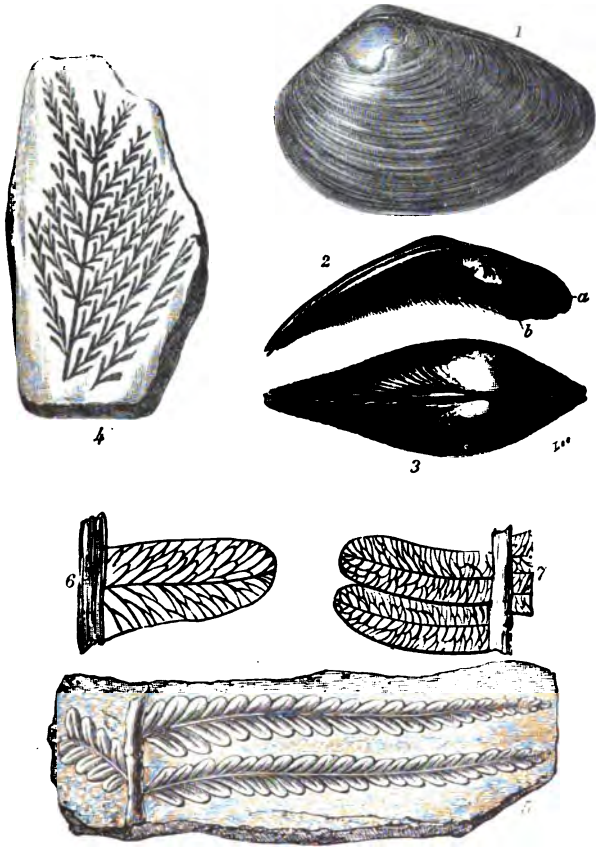



Fig. 87. Wealden Fossils.

1, 2, 3. Unio valdensis.
4. Sphenopteris Mantelli.
5. Lonchopteris Mantelli.
6, 7. Leaflets of Lonchopteris magnified.

## Fossils of the Shanklin Sands, Sandgate, and Folkestone Beds.

*Echinodermata.*—Peltastes Wrightii.

*Brachiopoda.*—Terebratula depressa, T. moutoniana, Waldheimia tamarindus, Terebratella Menardi, T. Fittoni, Rhynchonella antidichotoma.

*Lamellibranchiata.*—Ostrea macroptera, Pecten aptiensis, Venus parva, Plicatula carteroniana, Thetis Sowerbyi (minor).

*Gasteropoda.*—Aporrhais vectiana.

*Cephalopoda.*—None common.

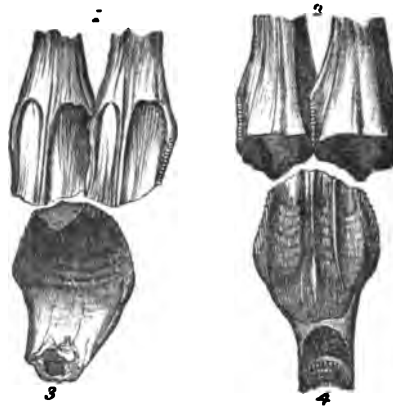



Fig. 88. Upper and lower Teeth of Iguanodon Mantelli.
1 and 3. Outer aspect. 2 and 4. Inner aspect.

In the Wealden we have an estuarine and freshwater fauna of Lower Cretaceous age, and the species which occur most frequently are the following:—

*Plantæ.*—Abietites Dunkeri, Endogenites erosa, Sphenopteris Mantelli, Lonchopteris Mantelli.

*Crustacea.*—Cypridea valdensis, C. spinigera, Cythere Fittoni, Estheria membranacea.

*Gasteropoda.*—Paludina fluviorum, P. sussexénsis.

*Lamellibranchiata.*—Cyrena media, C. parva, Unio valdensis.

*Fish.*—Lepidotus Mantelli.

*Reptiles.*—Iguanodon Mantelli, Ceteosaurus brevis, Hylæosaurus Owenii, Streptospondylus major, Chelone Mantelli.

*Mammals.*—None yet known, though it is certain that the descendants of the Purbeck Marsupials must have inhabited the country drained by the great river.

### 1. *The Wealden District.*

This district forms an oval-shaped area occupying portions of Kent, Surrey, Hants, and Sussex; on the north-west and south it is bounded by the escarpment of the chalk, but eastward it opens on to the English Channel between Eastbourne and Folkestone. The structure of this area is generally described as that of an anticlinal ridge, but in reality it more resembles that of an oval dome or inverted boat. The district known as the Bas Boulonnais in France is the eastern prolongation and termination of the Wealden area, and the English and French districts are undoubtedly continuous beneath the waves of the English Channel; before that channel was made they doubtless formed one continuous tract of land, just as they originally formed one area of deposition at the time when the Wealden beds were being accumulated.

A section across the Weald from north to south, and regarding only the Cretaceous rocks, will appear as in fig. 89, which is taken along a line drawn from Beachy Head to Chatham. A section from west to east would show a similar arrangement, but the actual length of country traversed would be four times that traversed in fig. 89. Fig. 91 is a section along the same line as fig. 89, but drawn to a much lower base-level, and showing not only the lie of the Cretaceous rocks, but that of the underlying Jurassic beds, and the probable position of the Palæozoic rocks under Chatham and the North Downs. The northerly thinning of the Lower Cretaceous strata has been proved

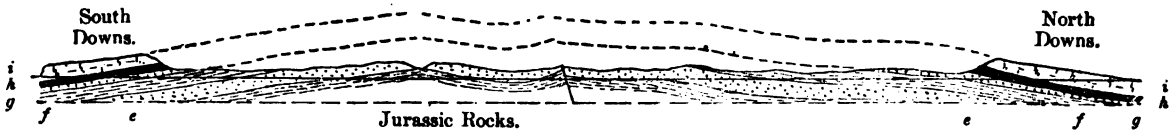



Fig. 89. Diagrammatic section across the Wealden area of Kent. Viewed from the east. Distance about 50 miles.

*i*. Chalk.
*h*. Upper Greensand and Gault.
*g*. Lower Greensand.
*f*. Weald Clay.
*e*. Hastings Sand.

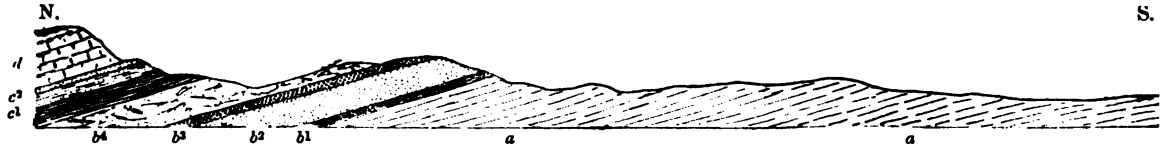



Fig. 90. Section through the Cretaceous Escarpments of Surrey. Viewed from the west. Distance about 9 miles.

*d*. Chalk (Lower and Middle).
$c^2$. Upper Greensand.
$c^1$. Gault.
$b^4$. Folkestone Beds.
$b^3$. Sandgate Beds.
$b^2$. Hythe Beds.
$b^1$. Atherfield Clay.
*a*. Weald Clay.

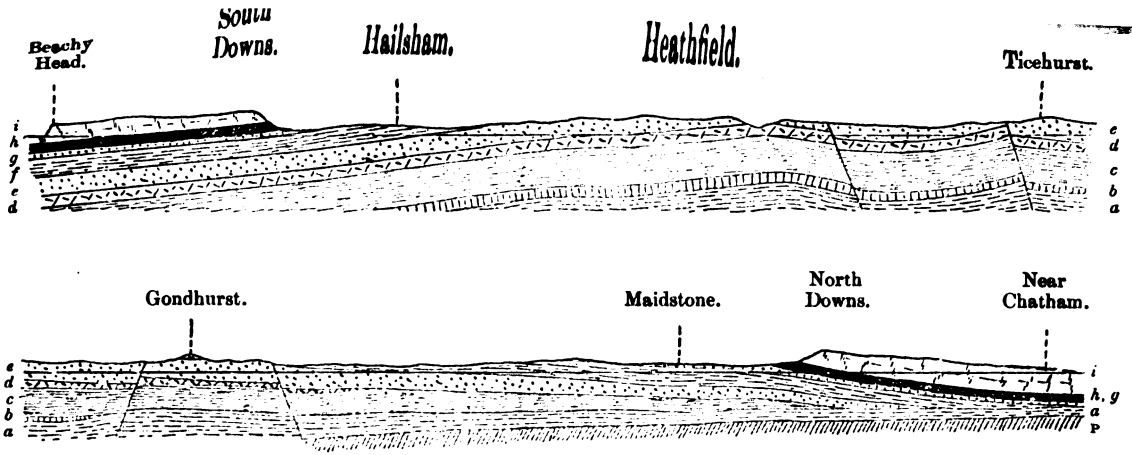



Fig. 91. Section across the Weald of Kent along the same line as that of Fig. 89. Horizontal scale, 4 miles to an inch.

*i*. Chalk.
*h*. Upper Greensand and Gault.
*g*. Lower Greensand.
*f*. Weald Clay.
*e*. Hastings Sands.
*d*. Purbeck Beds.
*c*. Portland and Kimeridge Clay.
*b*. Corallian Beds.
*a*. Oxford Clay.
P. Palæozoic Rocks.

by a recent boring at Chatham,[1] and this part of the section is reduced from that drawn by Mr. Whitaker.

The lower members of the Lower Cretaceous series in this area are of freshwater origin, and are known as the Wealden beds, because they occupy the larger portion of the district. The upper members are marine, and constitute what is known in England as the Lower Greensand.

| | | Max. thickness. |
|---|---|---|
| Lower Greensand (marine). | Folkestone beds | 160 |
| | Sandgate beds | 80 |
| | Hythe beds | 200 |
| | Atherfield clay | 60 |
| Wealden Beds (freshwater). | Weald clay | 1,000 |
| | Hastings sand, in three divisions | 1,000 |
| Purbeck beds below | | 400 |

**Hastings Sand.**—The three lower members of the Wealden group, being chiefly composed of sands, are usually classed together as the Hastings sand.

The Ashdown sand consists of soft buff or white sand and sandstone, which are 400 feet thick in Ashdown Forest, and form the high ground of Crowborough Beacon (800 feet high). Near Hastings and Fairlight the lower part of this sand is replaced by clays with interbedded sandstones (350 feet thick), which are surmounted by 150 feet of sand and sandstone. A few plant-remains are the only fossils.

The Wadhurst clay, though never more than 160 feet thick, is palæontologically important, as it is rich in fossils, and contains a bone-bed near Battle, from which many reptilian bones and teeth have been obtained. It consists of clays and shales, with bands of argillaceous ironstone near the base, and irregular layers of hard calcareous sandstone (Tilgate stone). The fossils are *Paludina fluviorum*, *Cyrena media*, *Lepidotus Mantelli*, *Hybodus dubius*, *Goniopholis crassidens*, *Iguanodon*, and *Megalosaurus*.

The Tunbridge Wells sands are lithologically similar to the Ashdown sands. Near Hastings they are only 150 feet,

[1] Described by Mr. Whitaker, "Quart. Journ. Geol. Soc.," vol. xlii. p. 26.

but the thickness increases steadily toward the west, a set of mottled clays and shales coming in at the same time in the middle of the sands, and becoming of sufficient importance to deserve a separate name, the Grinstead clay; this westerly thickening of the Tunbridge sands is shown in the following table:—

| | Cuckfield. | Ashdown Forest. | Heathfield. | Fairlight. |
|---|---|---|---|---|
| Upper sands . | 200 | 150 | 130 | 100 |
| Grinstead clay . | 80 | 50 | 20 | 10 |
| Lower sands . | 100 | 60 | 80 | 50 |
| | 380 | 260 | 230 | 160 |

At the top of the upper sands in the Cuckfield district, which is often called the Tilgate Forest, there are large concretionary masses of calcareous grit or sandstone, such as were termed Tilgate stone by Dr. Mantell. It was in these masses that the remains of *Iguanodon* and *Hylæosaurus* were first discovered by Dr. Mantell, and the specimens which he figured and described [1] are now in the South Kensington Museum.

Associated with the stone are thin layers of coarse conglomeratic grit, consisting of small pebbles, with broken bones, teeth, &c., cemented together by calcareous matter; in it the small round palatal teeth of *Lepidotus* are not uncommon.

**The Weald Clay.**—The upper member of the Wealden group consists mainly of brown and blue clays, with layers of shelly limestone and occasional beds of sand and calcareous sandstone. The limestones are known as Sussex marbles, and are composed almost entirely of *Paludina* shells; those in the lower part of the clay consisting chiefly of *P. sussexensis*, while the most constant band (the Petworth and Bithersden marbles) consists of *P. fluviorum*. The minute freshwater Crustaceans (*Cypridea*) are also very abundant in some places, the surfaces of the more shaly beds being crowded with them (see fig. 92). *Unios* and *Cyrenæ* also occur.

[1] "Fossils of the South Downs," "Medals of Creation," vol. ii., and "Fossils of the British Museum," p. 203.

The Weald clay, like the upper part of the Hastings sand, is thickest in the western and thinnest in the eastern part of the district. Below Leith Hill, west of Horsham, its thickness is estimated by Mr. Topley[1] at 900 to 1,000 feet; about Tunbridge it is 600 feet, and near Hythe it may not be more than 350 feet.

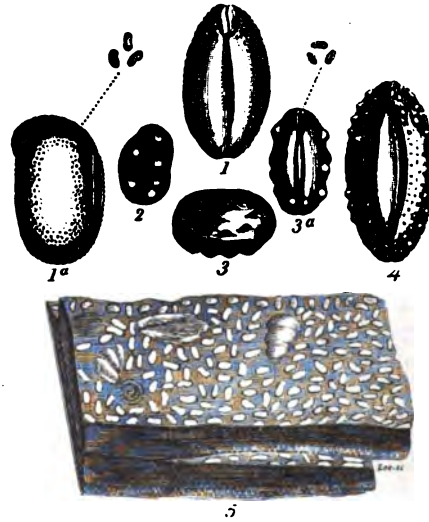



Fig. 92. Purbeck and Wealden Cyprides.

1. Cypridea valdensis.
2. Cythere Fittoni.
3. Cypridea tuberculata.
4. Cypridea granulosa.
5. Shaly clay enclosing Cyprides.

The uppermost beds at Haslemere, immediately below the Atherfield clay with *Panopæa*, contain shells of *Corbula* and *Mytilus*, together with *Cyrena* and *Melanopsis*, and indicate a change from freshwater to estuarine conditions.

**Lower Greensand.**—The beds between the Weald clay and the Gault clay (base of Upper Cretaceous) being

[1] "Geology of the Weald, Mem. Geol. Survey," p. 96.

chiefly of a sandy nature, and often coloured green by glauconite, they came to be known as the Lower Greensand, the similar sands above the Gault being at the same time called Upper Greensand.[1] The lithological characters of the beds composing the Lower Greensand in the Wealden district are very variable, but four subdivisions are recognized by the Geological Survey (see ante, fig. 90).

*The Atherfield Clay* is first seen in Kent opposite Shorncliffe Battery, but is only exposed at the lowest tides; thence it rises westward, running at first along the line of inland cliff to Aldington Knowl, and traceable thence all round the area occupied by the Weald clay. It can be seen in the railway cuttings at Sevenoaks and Red Hill, *Panopæa plicata*, *Exogyra sinuata*, *Perna Mulleti*, and *Trigonia dædalea* being common fossils; along this line it varies in thickness from 50 to 30 feet. At Haslemere it is 60 feet, and its juncture with the Wealden was observed by Mr. Salter, who says "the change from dark greyish-blue clay (Wealden) to the purely marine deposit of brown clay was marked no less by the fossils than by the change in the colour of the bed."[2] He found *Panopæa plicata* abundant within a few inches of the Wealden clay, and the shells of that bivalve were embedded in the vertical position which such molluscs occupy when alive. This shows how quiet and gentle was the change from estuarine to marine conditions of deposit.

*Hythe Beds.*—In the north-eastern part of the district between Hythe and Sevenoaks these beds consist of greenish-yellow sand, often marly or argillaceous, and hard bluish-grey calcareous sandstone, the soft beds being locally known as "hassock" and the hard beds as rag; the latter are quarried for lime-burning and building purposes, and when exported are known as Kentish Rag. The beds of rag and hassock alternate in regular layers, and these alternations are sometimes so frequent that no fewer than 28 such layers, or courses, have been counted in a vertical depth of 30 feet.

[1] This method of nomenclature is, however, a very bad one, especially as the so-called Lower "Greensand" is more often yellow and brown than green; for these sands therefore the name *Vectian* (from the Isle of Wight) has been proposed by the author.

[2] In Topley's "Geology of the Weald," Mem. Geol. Surv., p. 114.

Occasionally, beds of chert occur, and one of these, near Sevenoaks, is from 4 to 13 feet thick. At Hythe and Maidstone the total thickness is only from 70 to 80 feet, but at Sevenoaks it is 160, and thence it increases westward to about 200 near Godalming. At the same time the beds of rag become fewer, till the whole mass consists of sand and sandstone, generally light-yellow, specked with green.

In the south-west, about Midhurst and Petersfield, there are some beds of calcareous stone, but these die out to the eastward, and the whole group becomes rapidly thinner in that direction; at Hassocks Gate it is only 25 feet, and near Eastbourne both it and the Atherfield clay are absent.

The chief fossils of the Hythe beds are *Exogyra sinuata*, *Trigonia spinosa*, *Tr. ornata*, *Belemnites semicanaliculatus*, *Nautilus elegans*, *Ancyloceras Bowerbankii*, *A. gigas*, *Terebratula sella*, and *Crassatella robinaldina*.

*Sandgate Beds.*—These are a variable set of beds, but are generally more or less argillaceous. At and near Sandgate they consist of dark green clayey sand full of glauconite grains and about 70 feet thick; fossils are not numerous, but at the base, resting on the Hythe beds, there is frequently a layer of pebbles and phosphate nodules, with Brachiopods and other fossils in the state of casts.

Westward, by Ashford, Maidstone, and Sevenoaks, the Sandgate beds are very thin (10 to 20 feet), but include some beds of fuller's earth; they thicken again near Nutfield, where beds of fuller's earth, sandy clay, and soft sandstone occur about 50 feet thick.

West of Reigate they do not appear on the Geological Survey map, being supposed to thin out, but it is more probable that they pass into the Bargate beds, which consist of sands and hard calcareous grits (Bargate stone), with some thin layers of fuller's earth, and coarse pebbly beds at the base, containing phosphate nodules and many fossils; the whole thickness is about 50 feet. *Avicula pectinata* is a characteristic fossil of the Bargate stone; *Terebratula oblonga*, *T. depressa*, *Waldheimia tamarindus*, *Terebratella Fittoni*, *T. trifida*, and *T. Menardi* are some of the fossils occurring in the pebble beds, and with them are many fossils derived from the Oxford clay, which must

then have formed part of the shore-line north of Godalming.[1]

In Hants and West Sussex the Sandgate beds reappear in a more normal form, consisting of shaly clay at the top, with sand and sandy clay below. Near Pulborough these beds are 70 or 80 feet thick and contain several layers of large ferruginous concretions which enclose *Thetis Sowerbyi*, *Trigonia alæformis*, and other fossils. Before reaching Eastbourne, however, these beds seem to have thinned out, unless they are represented by the green clayey sand which there rests on the Wealden.

*Folkestone Beds.*—At Folkestone these consist of light-green and grey sand with beds of hard stone, partly siliceous and partly calcareous in composition, which have recently been described by Dr. J. Hinde as veritable sponge-banks—the sponges being of the siliceous Hexactinellid order, and their fine, needle-like spicules are clearly visible on weathered portions of the rock. Fossils are not abundant in these beds, except at the summit, where the soft green sand below the Gault contains a set of fossils which often occur elsewhere at the same horizon; these are *Ammonites mammillaris*, *Am. Beudantii*, *Inoceramus Salamomi*, *Panopæa plicata*, *Pecten striato-punctata;* this band being known as the zone of *Am. mammillaris*.

For a few miles inland the composition of the Folkestone beds is much the same, but west of Saltwood they begin to change their character; the cherty sponge-beds disappear, and the sands are chiefly white, yellow, and brown, current-bedded, and including irregular layers of ironstone. This is, in fact, their normal facies, which they preserve with little change all round the Wealden area, and consequently the name of Folkestone beds is not a very happy one. In Sussex they are generally yellow and white sands, with occasional thin bands of hard, ferruginous grit, which is locally known as Carstone.

### 2. *South-Western District.*

In the Isle of Wight, and on the coast of Dorset, the

[1] The Godalming section has been carefully described by Mr. Meyer in a paper read before the Geol. Assoc. in 1868.

Lower Cretaceous series is again brought to the surface by a sharp, upward curvature of the strata, the line of which strikes east and west, from Culver Cliff to Ballard Down and the Ridgeway.

**Wealden Beds** are exposed on both sides of the Isle of Wight. The lowest beds seen are those at Brook Point in Compton Bay, and consist of a pale sandstone overlain by red and green marls in which the broken trunks of pine-trees are so numerous that it would seem as if a raft of waterlogged trees had here sunk to the bottom, a frequent occurrence in the deltas of large rivers like the Mississippi; the spot is known to local geologists as the "pine-raft." The higher beds, a succession of variegated marls, or clays, with thin beds of sandstone, can be seen by walking along the coast to the southward; they have yielded bones and footprints of *Iguanodon* and other reptiles, and are about 300 feet thick. The highest beds between Brixton Bay and Atherfield Point are a set of grey shales with sandstones, and then sandy limestones in which a few marine fossils have been found, *Modiola*, *Cardium*, *Cerithium*, and *Exogyra sinuata*; these beds are 200 feet thick, and are correlated by Professor Judd with the Punfield beds described below, but if these latter belong to the Lower Greensand, as Mr. Meyer believes, this correlation cannot be correct. No one has since compared the two sections.

The most complete exposure of the Wealden series is found in Swanage Bay on the coast of Dorset, where it forms the low cliffs at the head of the bay between Purbeck marls and the Lower Greensand. All these strata dip at a considerable angle to the north, and Mr. Bristow informs me that the thickness of the Wealden group here is not less than 2,500 feet. The lower part consists of sands and sandy clays, with seams of ironstone and bands of calcareous grit; above are variegated clays with laminated sands and shales at the summit, the topmost bed, according to Mr. Meyer,[1] being a bed of ferruginous grit. In these beds teeth and bones of fish and Dinosaurian reptiles are not uncommon, while Cyprid crustaceans and plants abound in the shales.

[1] "Quart. Journ. Geol. Soc.," vol. xxix. p. 70.

The next exposure of the Wealden is in Worbarrow Bay, but here their thickness is only 725 feet; in Mewps Cove they measure 660 feet; in Lulworth Cove 462, and in Man-of-War Cove they are reduced to 172 feet. They are seen again at Osmington and at Ridgeway, but have not been traced beyond the latter locality.

Wealden Beds reach the surface again over a small space in the Vale of Wardour, but their thickness here is not known, and north of this they are completely hidden by the overlap of the higher Cretaceous rocks.

**Lower Greensand.**—Excellent sections of this series are found in the Isle of Wight; the clearest and best known of these is the cliff section between Atherfield Point and Rocken End at the south-west corner of the island. Dr. Fitton describes the following succession here:—

| | Feet. |
|---|---|
| 16. Yellow and white sands | 118 |
| 15. Grey clays and sand-rock | 118 |
| 14. Sands with hard ferruginous lumps | 20½ |
| 13. Green and yellow sands | 97 |
| 12. Shaly clay and ferruginous sands | 25 |
| 11. Greensand and clay | 20 |
| 10. Hard greensand and sandstone | 16 |
| 9. Green and grey sands | 42 |
| 8. Sand with nodules containing *Crioceras* | 46 |
| 7. Greenish sandy clay and brown clay | 57 |
| 6. Sands and clays with *Ancyloceras* nodules | 16 |
| 5. Brown sands with *Ancyloceras* nodules | 50½ |
| 4. Brown ferruginous sands | 32 |
| 3. The "Crackers"—sands and sandy clays, with large concretionary masses of calcareous grit | 85 |
| 2. Atherfield clay, grey and brown clays | 60 |
| 1. Perna Bed, dark argillaceous sandstone | 5 |
| | 808 |

It is not difficult to correlate Fitton's divisions with those established in Kent and Surrey. Nos. 1, 2, and 3 are the Atherfield beds, and they are the most fossiliferous beds of the whole series, *Perna Mulleti*, *Pinna robinaldina*, *Ammonites Deshayesii*, *Gryphæa sinuata*, *Trigonia caudata*, and *T. dædalea* being common. The overlying beds from 4 to 13 may be correlated with the Hythe beds; their principal fossils are mentioned on p. 374. Nos. 14 and 15 appear to correspond with the Sandgate beds (Pebble Beds and

Fuller's Earth of Godalming). The highest sands (16) are doubtless equivalent to the Folkestone beds.

The three uppermost divisions being well exposed near Shanklin on the eastern side of the island, are sometimes known as the "Shanklin sands." Adopting this name, we may divide the series into three groups, as below :—

| | Feet. |
|---|---|
| 3. Shanklin sands . . . . | 256½ |
| 2. Walpen sands (Hythe beds) . . | 401½ |
| 1. Atherfield beds . . . . | 150 |

In Dorset their thickness is much reduced, but is still some 250 feet thick at Punfield, in Swanage Bay, according to Mr. Meyer,[1] whose interpretation of the section there seems more probable than that of Professor Judd. Above the grit bed which Meyer takes at the base of the series are some 35 feet of dark argillaceous beds containing Atherfield fossils. These are succeeded by the strata which Professor Judd calls the Punfield beds, but which would appear to represent the Walpen sands of the Isle of Wight. They are about 160 feet thick; but the most important bed is a band of shale at the base, which contains a peculiar assemblage of fossils—*Vicarya Lujani, V. Pradoi, Cerithium Villanovæ, Actæon Esquerœ, Plicatula asperrima, Perna Rauliniana, Corbula striatula, Exogyra sinuata, Cardium subhillanum*, and *Ammonites Deshayesii* are some of these. The *Vicaryæ, Cerithia, Actæon*, and many other species occur in the Rhodanien beds of Spain, but are not known elsewhere in England. Above this band are yellow and ash-coloured sands with seams and bands of clay, and the uppermost beds are grey shales, containing *Cyrena* and *Cypris*. Above these Punfield beds are ferruginous sands and clays, which may be regarded as the Shanklin sands, and are about 60 feet thick.

In Worbarrow Bay there is a still further diminution of thickness; the Atherfield beds are absent; the Punfield beds are about 65 feet thick, and consist of light-coloured sands and clays; the Shanklin sands are about 40 feet.

[1] "Quart. Journ. Geol. Soc.," vol. xxix. p. 70; for Professor Judd's view, see "Q. J. G. S.," vol. xxvii. p. 207.

In Mewps Bay only the top of the Shanklin sands are seen faulted against the Wealden, and in Lulworth Cove no trace of them has been detected.

### 3. *Midland District.*

What is known as Lower Greensand in this part of England appears to be only the uppermost part of that formation, representing the Shanklin sands of the Isle of Wight, the Folkestone and Sandgate beds of the Weald. They rest unconformably upon the Upper Jurassic rocks, sometimes upon the Coral Rag, sometimes on Kimeridge clay, and sometimes on Portland or Purbeck beds. They vary greatly in thickness and in lithological characters, and are sometimes overlapped by the Gault, so that their outcrop is concealed for a space by that clay. Their range is thus broken up into a series of short tracts and patches.

**Seend and Faringdon Beds.**—These consist for the most part of soft yellow and brown sand, with some layers of sandstone and thin bands of ironstone, but at the base there are irregular beds of pebbly, fossiliferous gravel, compacted in places into a conglomerate. The pebbles are chiefly of quartz and porcellanous slate (lydianite). Among the fossils Sponges, Brachiopods, and Echinoderms are conspicuous, the following being some of these:—

| | |
|---|---|
| Terebratula tornacensis, | Peltastes Wrightii, |
| ,, depressa, | Goniopygus peltatus, |
| Waldheimia tamarindus, | Cidaris faringdonensis, |
| Terebratella Menardi, | Manon porcatum, |
| Rhynchonella nuciformis, | ,, faringdonensis, |
| ,, latissima, | Verticillites anastomosans. |

**Shotover Beds.**—The summit of Shotover Hill, south-east of Oxford, consists of ferruginous sands, with bands of ochre and cream-coloured loam, which contain remains of freshwater shells, *Unio*, *Cyrena*, and *Paludina*, some of which closely resemble Wealden species.[1] Similar beds occur at Wheatley and Brill, where they include beds of

[1] See Phillips, "Geology of Oxford," p. 412.

grey and lilac clay, and also at Stone, near Aylesbury; their exact stratigraphical position has not yet been determined. It is, however, very unlikely that they are really of Wealden age, and much more probable that they are fluviatile beds of a later date, contemporaneous with the marine sands which crop out from beneath the Gault at other places in Oxford and Bucks.

**Woburn Sands.**—Yellow and white sands emerge from beneath the Gault near Leighton Buzzard, and form a range of hills by Woburn and Ampthill to the neighbourhood of Shefford. Near their base are beds of phosphatic nodules, which are worked near Brickhill, and include casts of fossils derived from the underlying Jurassic clays, together with well-preserved contemporaneous fossils. Among the latter are—*Terebratula sella*, *T. depressa*, *T. microtrema*, *T. moutoniana*, and others, *Terebratella Menardi*, *Ter. Fittoni*, *Waldheimia celtica*, *W. tamarindus*, and others, *Peltastes Wrightii*, and many of the Faringdon sponges.[1]

The sands above are dug for glass-making purposes, and are believed to be about 200 feet thick near Woburn; they also contain a band of fuller's earth, which has been worked for more than a century.

These Woburn sands, passing beneath the valley of the Ivel, become conspicuous again near Sandy and Potton, with the same nodule beds near the base, in which derived reptilian bones are very abundant; thence the sands run through Cambridgeshire to the Fens south of Ely, near Streatham and Upware.

**Upware Beds.**—Banked against the Corallian limestones which form this island in the Fens are sands and silts with two nodule beds similar to those of Brickhill and Potton, but containing a still larger number and variety of fossils. The whole group here is less than 12 feet thick, and is overlain by the Gault, so that it seems on the point of thinning out. Besides the species previously quoted from Brickhill, there are here a number of Gasteropod and bivalve Mollusca which do not occur in Bucks, though some of them, such as *Opis neocomiensis*, *Pecten ornithopus*, and *Lima Faringdonensis* appear at Faringdon. Reptilian

[1] Keeping, "Fossils of Upware and Brickhill, Cambridge," 1883.

bones also occur here, and though many are derived, Mr. Keeping thinks some are indigenous, especially the Iguanodon and Crocodilian remains.

### 4. *Northern District.*

In Yorkshire and Lincolnshire the Lower Cretaceous series exhibits a more complete succession of marine deposits than is found in the southern or midland counties. Our knowledge of them is chiefly due to Professor Judd,[1] but the Lincolnshire beds have been mapped by the Geological Survey.[2] They emerge from beneath the Red Chalk near Caistor, and extend thence in a gradually widening strip to the neighbourhood of Spilsby and Candlesby at the south end of the Lincolnshire Wolds. In Yorkshire the whole series is argillaceous, but in Lincolnshire portions of it are arenaceous. The type section is found at Speeton Cliff in Yorkshire.

**Lower Group.**—At the base of this, both in Yorkshire and Lincolnshire, there is a bed of phosphate nodules containing rolled casts of fossils derived from the Upper Jurassic clays. Above this at Speeton are dark shaly clays which are divisible into three zones, as below:—

| | | Feet. |
|---|---|---|
| 3. | Zone of *Ammonites speetonensis* . . | 100 |
| 2. | „ „ *noricus* . . | 50 |
| 1. | „ „ *astierianus* . . | 50 |

The lowest zone also contains *Am. multiplicatus, Am. fasciculatus, Belemnites lateralis, Exogyra Couloni,* and *Tozaster complanatus.*

In Lincolnshire these clays, or at any rate the two lower zones, are represented by soft yellow and grey sands (Spilsby sands), including large blocks or doggers of calcareous sandstone, which are rich in fossils—*Belemnites lateralis, Am. plicomphalus, Am. multiplicatus* (?), *Pecten orbicularis,* var. *magnus, Trigonia robinaldina,* and other *Trigoniæ,* allied more to Jurassic than to Cretaceous forms.

[1] "Quart. Journ. Geol. Soc.," vol. xxiii. p. 227, and vol. xxiv. p. 218.
[2] "Mems. Geol. Survey, Explanations of Sheets 83 and 84."

**Middle Group.**—At Speeton this consists entirely of clay, and is 150 feet thick; at the base is a zone in which *Ancyloceras Duvalii* and *Am. bipinnatus* are abundant, and at its top is a layer of dark brown septarian nodules, in which remains of the small lobster-like crustacean *Meyeria ornata* are found. Above this are clays, with *Pecten cinctus*, *Exogyra sinuata*, and *Belemnites jaculum*.

Near Tealby in Lincolnshire this group consists of clays, limestones, and ironstones, which are called the Tealby beds by Professor Judd; the large *Pecten cinctus* is the most distinctive fossil of these beds, but all the Speeton

Fig. 93. Meyeria ornata.

species just mentioned also occur, together with *Trigonia ingens*, *Terebratula tornacensis*, *Ostrea macroptera*, and *Rhynchonella parvirostris*. South-east of Tealby the limestones die out; and about Dalby and Scremby, near Spilsby, the group consists of the following beds:—

| | Feet. |
|---|---|
| Soft marly and oolitic ironstone ("roach") | 40 |
| Dark blue clays . . . . . | 100 |
| Hard oolitic ironstone . . . | 2 to 12 |

It is possible that the lowest ironstone, and part of the blue clay above, belongs to the zone of *Am. speetonensis*, as that Ammonite occurs in this clay near Donnington.

**Upper Group.**—At Speeton this also consists of clay; at the base is a band of light blue clay (about 30 feet thick), containing large septaria or cement-stones; in these are

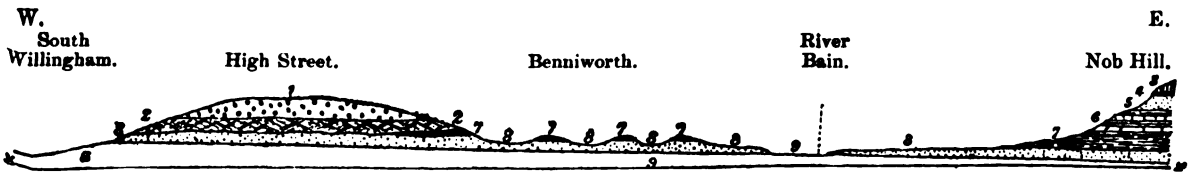



Fig. 94. Section through the Lower Cretaceous Series of Lincolnshire, near Donnington. Distance 3 miles.
Drawn by Mr. A. Strahan, and lent by the Council of the Geologists' Association.

*x*. Sea Level.
1. Boulder Clay.
2. Glacial Sand and Gravel.
3. Lower Chalk.
4. Red Chalk.
5. Carstone.
6. Tealby Limestone.
7. Donnington Clay.
8. Spilsby Sandstone.
9. Kimeridge Clay.

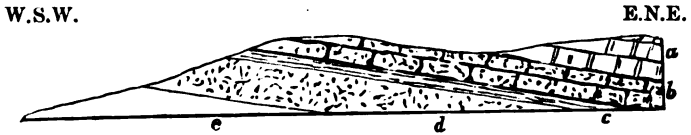



Fig. 95. Section through Lodge Hill, Snettisham, Norfolk (by J. J. H. Teall). Distance three-quarters of a mile.

*a*. Lower Chalk.
*b*. Carstone.
*c*. Clay.
*e*, *d*. Lower Sands.

many fossils—*Belemnites semicanaliculatus, Ammonites nisus, Am. Deshayesii, Ancyloceras grande, Plicatula placunea, Perna Mulleti, Thetis minor, Thracia Phillipsii, Terebratula sella.* Above the Cement-stone beds there is blue clay (50 feet), with very few fossils, the whole fauna consisting of *Belemnites sp., Rhynchonella sulcata,* and *Vermicularia Phillipsii;* this passes up into black clay, with *Belemnites minimus,* which is elsewhere a fossil of the Gault.

In Lincolnshire no clay containing such a fauna has been met with; the group is either absent or represented by the coarse brown sandstone which immediately underlies the Chalk, and which attains a maximum thickness of 40 feet. No fossils have yet been found in this sandstone, but it is provisionally classed as the topmost member of the Lower series.

Of these three groups the lowest is unquestionably older than any other marine bed in England, and is doubtless the marine equivalent of a portion of the Wealden. It appears to be homotaxial with the upper part (Hauterivien) of the true Neocomien of the Franco-Swiss area, the yellow marls of Hauterive and Morteau with *Am. radiatus, Am. astierianus,* and *Toxaster complanatus.* The middle group is correlated by Professor Judd with the Urgonien, though in the abundance of *Crustacean* remains, *Exogyræ* and *Ancyloceras,* it resembles the Atherfield beds. The Cement-stone fauna indicates a still higher horizon, and can almost be matched with that of the Hythe beds; it would appear to be a deep-water fauna of Aptien age, while our other Aptien beds are shallow-water deposits, and therefore contain a somewhat different assemblage of fossils.

In Norfolk there is a series of ferruginous sands and sandstones, which occupy the place of the beds above described, and are known as the Carstone series, but so few fossils have been found in them that correlation is difficult; there can be little doubt, however, that the upper Carstone seen at Hunstanton is the same as the upper brown sandstone of Lincolnshire. Below this at Heacham is a band of clay which may represent the Tealby clay. The age of the lower sands, which occupy a large area near Sandringham, it is impossible to guess, but lithologically they resemble those of Sandy and Woburn.

### 5. *The Lower Cretaceous of France.*

D'Orbigny was the first to establish palæontological subdivisions in the Cretaceous system of France, and most French geologists still adhere to his classification, though various modifications have been proposed. In the Lower series he made three subdivisions, naming them Neocomien, Urgonien, and Aptien, and there really seems no occasion for changing this nomenclature.

In the north of France the most complete section appears to be that of Vassy in Haute-Marne; this is as follows, and the fact of freshwater beds occurring in the Urgonien is of much interest:—

| | |
|---|---|
| Aptien, 126 feet. | Greensand, with *Ostrea arduennensis.*<br>Yellowish sandstone, with *O. aquila.*<br>Clays, with *Plicatula placunea.*<br>The red bed (*couche rouge*), with *Toxaster oblongus.* |
| Urgonien, 118 feet. | Freshwater sands and sandstones. Freshwater mottled clays.<br>Clays, with *Ostrea Leymerii.* |
| Neocomien, 35 feet. | Limestone, with *Toxaster complanatus.*<br>Black clay and ferruginous sands. |

In the Jura the red bed of Vassy is represented by yellow marls, with a limestone at the base; this stage has been separated by Professor Renevier, under the name of *Rhodanien*, and he correlates it with the lower part of our Lower Greensand, Atherfield clay, &c. The lower part of the Urgonien is there represented by thick marine limestones, containing *Caprotina ammonia.* The section of this marine formation at the Perte du Rhone in the Jura is as follows:—

| | |
|---|---|
| Aptien, 20 feet. | Greensand, with *Am. mammillaris.*<br>Sandstone, with large bivalves.<br>Sands, with *O. aquila* and *Pl. placunea.* |
| Rhodanien, 56 feet. | Marls, with *Orbitolites lenticulata* at the base.<br>Marls, with *Trigonia caudata, Aporrhais robinaldina,* and *Heteraster oblongus.*<br>Red limestone, with *Pterocera pelagi* and *Diceras Lonsdalei.* |

| | |
|---|---|
| Urgonien, 340 feet. | Grey and white limestones, with *Caprotina ammonia*. |

No lower beds are seen here, but further south the underlying Neocomien beds are found to comprise—

| | |
|---|---|
| Neocomien. | Marls, with *Toxaster complanatus*.<br>Limestone, with *Ancyloceras Duvalii*.<br>„ „ *Belemnites dilatatus*.<br>Limestone of Fontanil.<br>Marls, with *Belemnites latus*.<br>Marls and limestones, with *Am. astierianus*.<br>Limestone, with *Terebratula diphyoides*. |

These beds are said to be several thousand feet thick in the south of France; the upper limestones having a thickness of 1,600 feet near Chambery, and the lower marls and limestones being some 1,800 feet thick. They constitute the normal marine type of which our Wealden beds are the freshwater representatives.

## § B. Upper Cretaceous Series.

The following is a tabular view of the larger zonal divisions into which this series can be subdivided, and may be used by the student as a table of reference in reading the subsequent more detailed descriptions:—

| | | |
|---|---|---|
| | Maestricht chalk . . . | Danien. |
| Upper Chalk. | Zone of *Marsupites*,<br>Zone of *Belemnitella mucronata*,<br>Zone of *Micrasters*, with hard rock at the base, | Senonien. |
| Middle Chalk. | Zone of *Holaster planus*, with chalk rock at the top,<br>Zone of *Terebratulina gracilis*,<br>Zone of *Rhynchonella Cuvieri*, with Melbourn rock at base, | Turonien. |

| | | |
|---|---|---|
| Lower Chalk. | Zone of *Belemnitella plena*,<br>Zone of *Holaster subglobosus*, with Totternhoe stone at base,<br>Zone of *Rhynchonella Martini*, with Chloritic marl at base, | Cenomanien. |
| Upper Green Sand and Gault. | Zone of *Pecten asper*,<br>Zone of *Ammonites rostratus*,<br>Zone of *Am. lautus* and *interruptus*, | Albien. |

The following are the characteristic fossils of the major divisions :—

## Fossils of the Gault and Upper Greensand.

*Spongida.*—Siphonia pyriformis, S. lobata.

*Actinozoa.*—Trochocyathus conulus, Cyclocyathus Fittoni.

*Echinodermata.*—Holaster lævis, Hemiaster Bailyi, H. Murchisoniæ, Peltastes clathratus.

*Brachiopoda.*—Terebratula biplicata, Terebratella pectita, Rhynchonella compressa.

*Lamellibranchiata.*—Inoceramus sulcatus, I. concentricus, Avicula gryphæoides, Exogyra conica, Gryphæa vesiculosa, Nucula pectinata, Cardium Hillanum, Pectunculus umbonatus.

*Gasteropoda.*—Solarium ornatum, Natica gaultina, Pleurotomaria Rhodani, Aporrhais Parkinsoni, Ornithopus retusus, Turritella granulata, Dentalium decussatum.

*Cephalopoda.*—Ammonites interruptus, Am. lautus, Am. splendens, Am. auritus, Am. rostratus, Hamites attenuatus, Turrilites Hugardianus, Belemnites minimus.

## Fossils of the Lower Chalk.

*Spongida.*—Plocoscyphia mæandrina, Dendrospongia fenestralis.

*Echinodermata.*—Holaster subglobosus, Discoidea cylindrica, Cidaris dissimilis.

*Brachiopoda.*—Terebratula semiglobosa, Rhynchonella Martini, Rh. mantelliana.

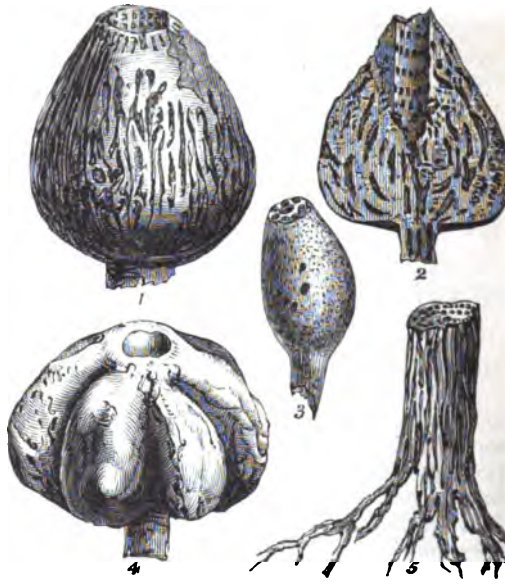



Fig. 96. Siphoniæ from Upper Greensand.

1, 2. Siphonia pyriformis.
3. ,, sp. (? young).
4. ,, lobata.
5. ,, stem and radicles.

*Lamellibranchiata.*—Inoceramus latus, Plicatula inflata, Pecten Beaveri, P. fissicosta, Lima globosa, Spondylus striatus.

*Cephalopoda.*—Ammonites varians, Am. rhotomagensis, Am. Mantelli, Turrilites costatus, T. tuberculatus, Scaphites æqualis, Belemnitella plena.

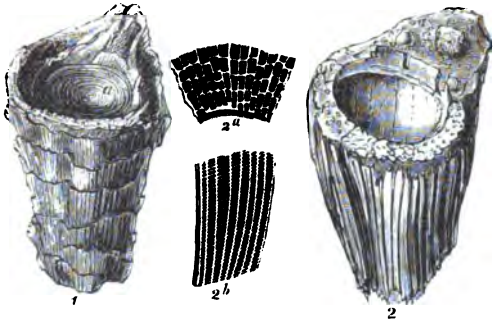



Fig. 97. Rudistæ from the Chalk.

1. Sphærulites with opercular valve (*a*), (Turonien, France).
2. Radiolites Mortoni, Lower Chalk, Lewes ($\frac{1}{3}$).
2*a*, 2*b*. Transverse and vertical sections magnified.

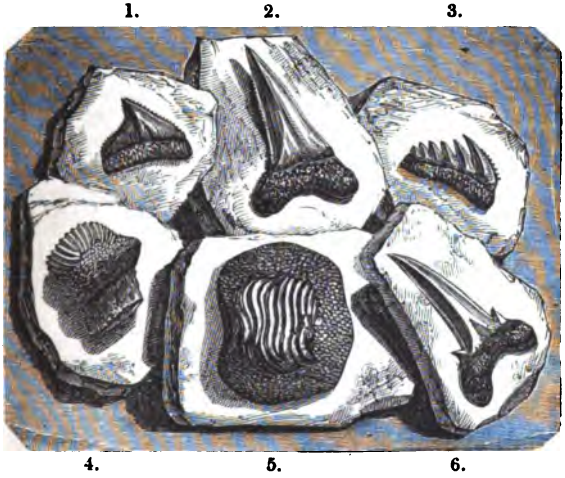



Fig. 98. Sharks' Teeth from the Lower Chalk.

1. Corax pristodontus.
2. Oxyrhina macrorhiza.
3. Notidanus microdon.
4. Ptychodus polygurus (side).
5. „ „ (surface).
6. Otodus appendiculatus.

## Fossils of the Middle Chalk.

*Echinodermata.*—Galerites subrotundus, Cardiaster pygmæa, Discoidea minima, Cidaris hirudo, Holaster planus.

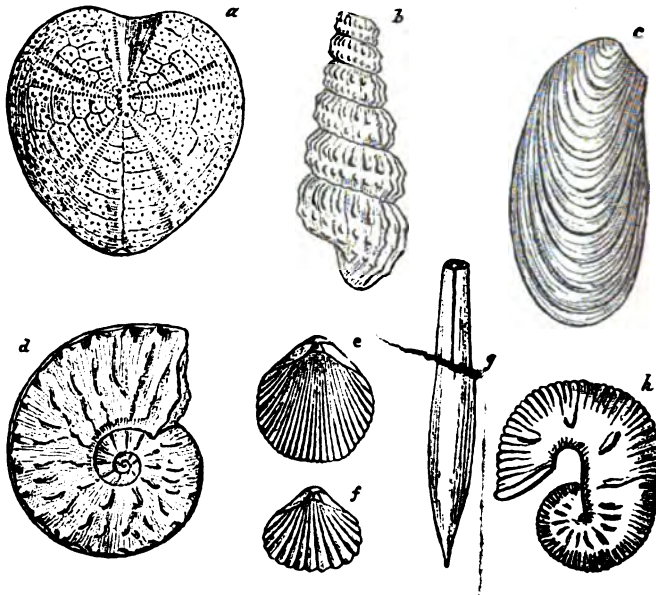



Fig. 99. Lower and Middle Chalk Fossils.

*a.* Holaster subglobosus, ½.
*b.* Turrilites costatus, ½.
*c.* Inoceramus mytiloides, ½.
*d.* Ammonites varians, ½.
*e.* Rhynchonella Cuvieri, *nat. size.*
*f.* „ mantelliana, ½.
*g.* Belemnitella plena, ½.
*h.* Scaphites æqualis, ½.

*Brachiopoda.* — Terebratula semiglobosa, Rhynchonella Cuvieri, Terebratulina gracilis.

*Lamellibranchiata.*—Inoceramus mytiloides (labiatus), I. Brongniarti.

*Cephalopoda.*—Am. nodosoides, Am. peramplus, and var. Prosperianus.

## Fossils of the Upper Chalk.

*Spongida.*—Ventriculites quincuncialis, Siphonia Kœnigi.
*Echinodermata.*—Galerites conicus, Micraster cor-bovis,

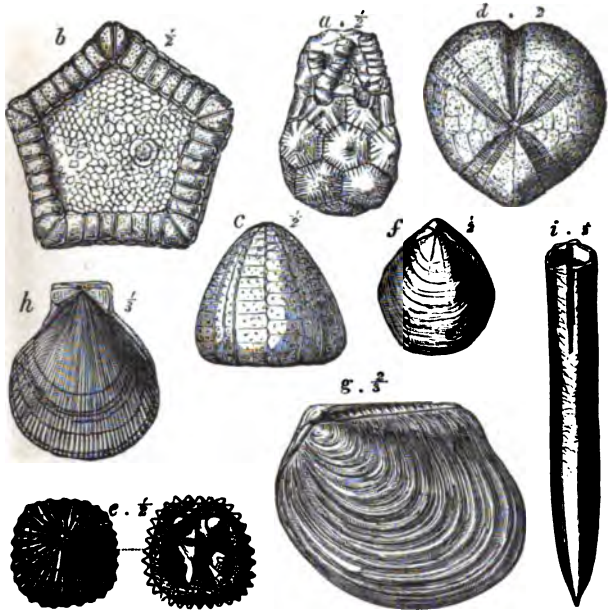



Fig. 100. Upper Chalk Fossils.

*a.* Marsupites ornatus.
*b.* Goniaster Parkinsoni.
*c.* Galerites conicus.
*d.* Micraster coranguinum.
*e.* Crania Ignabergensis.
*f.* Terebratula carnea.
*g.* Inoceramus Lamarckii.
*h.* Pecten nitidus.
*i.* Belemnitella mucronata.

M. coranguinum, Marsupites ornatus, Ananchytes ovatus, Goniaster Parkinsoni, Bourgeticrinus ellipticus.

*Brachiopoda.*—Crania Ignabergensis, Terebratula carnea, Rhynchonella octoplicata, Magas pumila.

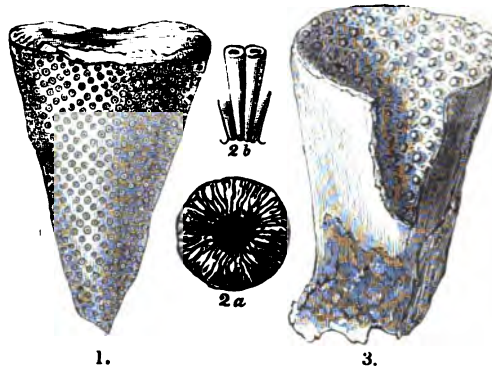



**Fig. 101. Ventriculites quincuncialis.**

1. The Ventriculite preserved in flint.
2*a*. A transverse section of 1. 2*b*. Structure magnified.
3. The external mould or flint encasement.

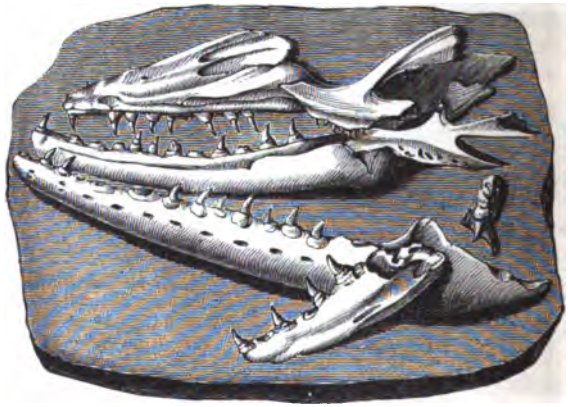


**Fig. 102. Mosasaurus Hoffmanni ($\frac{1}{18}$).**
**Upper Chalk, near Maestricht, Belgium.**

*Lamellibranchiata.*—Pecten nitidus, Lima Hoperi, Spondylus spinosus.

*Cephalopoda.*—Belemnitella mucronata, B. vera, Ammonites leptophyllus.

### Stratigraphy.

The rocks of the Upper Cretaceous series occupy a far larger surface area in England than those of the Lower series, but for the purposes of description their range may be divided into the same four geographical districts, namely, South-eastern, South-western, Midland, and Northern.

#### 1. *South-Eastern District.*

The general structure of the Wealden area is shown in figs. 89 and 90, and the outcrops of the several divisions between the Lower Greensand and the Upper Chalk of the North and South Downs are continuous all round the area.

**Gault and Upper Greensand.**—The Gault of Folkestone has been studied in detail by Mr. F. G. H. Price,[1] who divides it into Lower and Upper Gault, with a passage bed between containing two layers of phosphate nodules and fossils derived from the lower beds. There is also a layer of phosphatic nodules at the base of the Lower Gault separating it from the Folkestone sands. The Lower Gault consists of blue clay about 30 feet thick, and is divisible into seven zones, but these merely indicate the local distribution of the fossils and cannot be distinguished elsewhere. The characteristic Ammonites are *interruptus, auritus, lautus,* and *denarius.* The Upper Gault is 70 feet thick, and consists of a pale grey marly clay, in the upper part of which is a band of dark argillaceous greensand 3 feet thick. The principal fossils of the Upper Gault are *Am. rostratus, Am. varicosus, Am. cristatus, Inoceramus sulcatus, Avicula gryphæoides, Plicatula pectenoides, Kingena lima, Terebratula biplicata.* No representative of the Upper Greensand is found at Folkestone, the glauconitic

[1] "Quart. Journ. Geol. Soc.," vol. xxx. p. 342.

marl above belonging apparently to the base of the Chalk marl, and resting unevenly upon the Gault as if there had been some erosion of the latter.

Inland the thickness of the Gault becomes much greater and is not less than 200 feet near Maidstone, but the chief part of this appears to be Lower Gault, and the absence of the Upper Greensand is still more apparent, for at the Aylesford brickyard Gault clay with *Am. varicosus* is overlain by Chalk marl, with a thin layer of glauconitic marl and phosphate nodules at its base.

It is not till we reach the neighbourhood of Westerham that anything like typical Upper Greensand makes its appearance; this consists of soft green sand above, and calcareous sandstones below, the latter often passing into the fine-grained siliceous stone which is known as "malm" or "firestone," and is largely composed of sponge spicules;[1] the whole is about 30 feet thick between Merstham, Reigate, and Dorking.

Still further west, in the neighbourhood of Alton and Selborne, the succession is given as follows:[2]—

Chalk marl passing down into "chloritic marl."
Compact chalky "Malm-rock," with some beds of hard ragstone.
Softer sandy "malm," passing into a mottled marly clay, which passes down into the Gault.

These "malm beds" thin out to the south-west below the South Downs, and are replaced by soft marls and sands. They and the firestone beds are supposed to belong to the zone of *Pecten asper*, which occurs in France above the zone of *Ammonites rostratus*. At Eastbourne these beds are absent, and the section is similar to that of Folkestone, but is not now accessible.

**Lower Chalk.**—In the cliffs between Folkestone and Dover the following zones have been recognized by Mr. F. G. H. Price:[3]—

| | Feet. |
|---|---|
| 4. Yellow shaly chalk, with *Belemnitella plena* . . . . . | 4 |
| 3. Greyish white chalk, with *Holaster subglobosus* and *Discoidea cylindrica* . . . . . | 148 |

[1] Dr. Hinde on "Beds of Sponge Remains," Phil. Trans., 1885, p. 403.
[2] Topley, "Geology of the Weald, Mem. Geol. Surv.," p. 157.
[3] "Quart. Journ. Geol. Soc.," vol. xxxiii. p. 431.

| | Feet. |
|---|---|
| 2. Chalk marl, with *Am. rhotomagensis* and *Am. varians*, *Turrilites costatus*, *Rhynch. Mantelliana*, and many other fossils; near the base several reefs of sponges—*Plocoscyphia meandrina*, &c., occur | 32 |
| 1. Dark green glauconite marl, with *Stauronema Carteri* and *Plocoscyphia meandrina* | 14 |

At the top of the Chalk marl there is a soft mottled bed which is very rich in fossils, no fewer than fifty-six species being quoted by Mr. Price.

A very similar section is found between Eastbourne and Beachy Head, but the *Stauronema* beds there contain numerous phosphatic nodules, and are about 30 feet thick.

Inland there are few complete sections, and little is yet known regarding the composition of the Lower Chalk in Hampshire, Surrey, or Kent.

**Middle Chalk.**—The Dover section has recently been examined by Mr. W. Hill,[1] who finds the beds correspond closely with the divisions which had been previously made in the Midland counties. The following are the zones recognized with their characteristic fossils, and the thickness assigned to each:—

| | Feet. |
|---|---|
| 3. Zone of *Holaster planus*, hard white lumpy chalk, with two marked lines of flints near the top and a band of scattered flints below | 22 |
| 2. Zone of *Terebratulina gracilis*, soft white chalk, with some flint nodules and thin bands of marl in the upper part, *Ter. gracilis* and teeth of *Ptychodus decurrens* | 150 |
| 1. Zone of *Rhynchonella Cuvieri*, in two divisions, firm white chalk above, with *Galerites subrotundus* passing down into hard gritty nodular chalk, which is very hard at the base. *Rh. Cuvieri*, *Discoidea minima*, and *Inoceramus mytiloides* occur throughout | 70 |

The hard rock at the base of the division, which rests on the Belemnite marl, is certainly equivalent to the Melbourn Rock of Cambridge and Herts (see p. 415); and the lumpy rocky chalk of the *Holaster planus* zone appears to be on the same horizon as the Chalk rock of the Thames Valley.

**Upper Chalk.**—The chalk of this division forms the

[1] "Quart. Journ. Geol. Soc.," vol. xlii. p. 232.

cliffs near Dover, Walmer, and Deal, and those round the Isle of Thanet. It is divisible into three portions or zones, which differ both in lithological character and in fossil contents; these are, in descending order :—

3. Zone of Marsupites.
2. „ *Micraster coranguinum.*
1. „ *Micraster cortestudinarium.*

1. The lowest forms the summit of Shakespeare Cliff, and comes down to the sea-level at St. Margaret's Bay near Dover; it consists of loose chalk, with many layers of hard semi-crystalline lumps or nodules, and includes a band of very hard yellowish gritty rock some 12 feet thick; flints are few and scattered, except near the top, where they begin to be arranged in lines. In these beds *Micraster breviporus* and *M. cortestudinarium* are common fossils; *Ammonites prosperianus, Rhynchonella octoplicata, Rh. reedensis* and *Trochus gemmatus* are also found. This division is about 80 feet thick, according to Mr. Hill.

2. The succeeding chalk is whiter and softer; it contains numerous lines of flint nodules, and also continuous floors of flint several inches thick. Fossils are less abundant, but *Micraster coranguinum, Rhynchonella subplicata, Lima Hoperi,* and others occur. This chalk is found again at Broadstairs.

3. The uppermost zone consists of soft white chalk *without* flints; it caps the flint-bearing chalk near Deal and forms the cliffs near Margate; in it the plates of *Marsupites* (*M. Milleri* and *M. ornatus*) are common fossils, together with *Belemnites quadrata, B. vera, Galerites conicus, Micraster coranguinum* and spines of Cidaris. *Ananchytes ovatus* is found throughout the Upper Chalk from base to top.

It is not certain whether the chalk with *Belemnitella mucronata* occurs in the Isle of Thanet.

A similar succession can be traced in the chalk cliffs between Beachy Head and Brighton, and an excellent description of these sections is given by Dr. Ch. Barrois in his Memoir on the Upper Cretaceous Rocks of Great Britain.[1]

[1] "Mems. de la Soc. Geol. du Nord," 1876, p. 18-28.

### 2. *South-Western District.*

In this I include the Isle of Wight and the counties of Hampshire, Wiltshire, Dorset, and Devon. It contains some of the best known sections of the Cretaceous series, those of the Isle of Wight being probably the most complete exhibition of the series in Britain. As the strata are traced westward their thickness gradually diminishes, and their characters undergo considerable modification as they approach what was clearly the shore-line of the period in Devonshire. The Gault and Upper Greensand overlap the Lower Greensand, and overstep the several members of the Jurassic system till they come to rest upon the Trias.

The general structure of the Isle of Wight is shown in the transverse section, fig. 103; the Chalk forms the central ridge of the island from Culver Cliff to the Needles, with an increasing northerly dip; from beneath the Chalk crop out the Upper Greensand and Gault, and the whole series once extended over the flattened arch of the Lower Greensand, but has everywhere been removed except in the extreme south of the island, where the Gault and Greensand, capped in places by the Lower Chalk, form the Downs above the Undercliff.

**Gault and Upper Greensand.**—Good exposures of these beds are visible at either end of the Undercliff of the Isle of Wight, viz., Ventnor and below St. Catherine's Down. At the former place the descending section is as follows:—

| | | Feet. |
|---|---|---|
| Upper Greensand. | 7. Chert beds—alternations of green sandstone and blue chert, *Pecten interstriatus, Vermicularia concava*, and *Siphonia* | 24 |
| | 6. Grey sandstones, with bands of hard rag, *Am. rostratus* | 18 |
| | 5. Yellow and reddish sandstones, with bands of rag | 30 |
| | 4. Soft yellow micaceous sands, with calcareous concretions, *Am. rostratus, Rhynch. latissima, Ostrea conica, Cardiaster fossarius*, and other fossils | 30 |
| Gault. | 3. Hard blue rag | 1 |
| | 2. Bluish-grey sandy and micaceous clay, few fossils | 55 |
| | 1. Dark blue clay, with a few Gault fossils | 100 |
| | | 258 |

The two lower divisions are usually called Gault, and the

higher beds Upper Greensand, but many of the fossils of the Upper Gault of Folkestone occur here in the sands (No. 4). Dr. Barrois places the Chert beds in the zone of *Pecten asper*, but that fossil does not seem to occur in them.

In the Isle of Purbeck, at Punfield, and at Lulworth Cove a similar set of beds are found, but the Gault clays are much thinner (only 60 or 70 feet); above are green glauconitic sands with bands of rag (66 feet), surmounted by 10 feet of green sand with *Pecten asper*.

Further west, near Lyme Regis, the Gault clay thins out entirely or passes into greenish sandy clays. At and near Beer Head the section is as follows, according to Mr. Meyer [1] and Dr. Ch. Barrois: [2]—

| | Feet. |
|---|---|
| 3. Yellowish sandstone, with green grains, *Pecten asper*, *Terebratella pectita*, *Rhync. convexa*, &c. (Warminster beds) . . . | 20 |
| 2. Light coloured sands, with bands of chert, *Exogyra columba*, *Pecten 4-costatus*, and *Orbitolina concava* . . . . . | 74 |
| 1. Dark grey and greenish argillaceous sand, with *Inoceramus sulcatus*, *Pectunculus umbonatus*, and *Hemiaster Murchisoniæ* (Blackdown beds) . . . . . | 58 |

At Blackdown and Haldon, in Devonshire, outliers of the Cretaceous sands rest upon the Trias, and these have been recently described by the Rev. W. Downes.[3] He concludes that the mass of the Blackdown beds do not occur at Haldon, the lowest beds there being the uppermost beds of Blackdown. The true Blackdown beds, with *Trigonia alæformis*, *Pectunculus umbonatus*, *Inoc. sulcatus*, &c., are 75 feet thick; they consist of yellowish brown sands and sandstone with concretions, used for making "whetstones." Above these is sand with bands of chert, which is 35 feet thick at Haldon, and is overlain by jaspery rock full of fossils, sand, and chert, with *Orbitolina concava* (16 feet in all); these might be called the Haldon beds, and they evidently correspond to the Chert beds (No. 2) of Dorsetshire.

When traced northward into Wiltshire the group pre-

[1] "Quart. Journ. Geol. Soc.," vol. xxx. p. 369.
[2] "Recherches," p. 69.
[3] "Quart. Journ. Geol. Soc.," vol. xxxviii. p. 75.

sents a different aspect, and consists of (1) Gault clay, varying in thickness; (2) soft grey micaceous sandstone with few fossils, 30 feet; (3) soft glauconitic sands with many fossils, about 20 feet. These last are known as the Warminster beds.

**Lower Chalk.**—In the Isle of Wight this is over 100 feet thick, consisting of the following beds, according to Barrois:—

| | Feet. |
|---|---|
| Grey chalk in regular beds, with *Holaster subglobosus* and *Am. rhotomagensis* | 90 |
| Chalk marl, with *Scaphites æqualis*, *Am. varians*, *Am. Mantelli*, *Turrilites costatus*, and a "sponge bed" with *Plocoscyphia mæandrina* at the base | 20 |
| Chloritic marl, with green grains and many fossils in phosphate, *Turrilites Morrisii*, and *Stauronema Carteri* | 6 |

The zone of *Bel. plena* has not been recognized here, but it is seen in the sections on the Dorset coast, that fossil occurring in a band of greenish marl two to six feet thick. This is underlain by about 40 feet of compact marly chalk, and at the base is "Chloritic marl." The Chalk marl proper appears to have thinned out, but here and further west the "Chloritic marl" contains *Holaster subglobosus*, and it may be that this glauconitic marl is not a definite horizon, but only a basement bed formed along a sloping surface, and eventually representing only the higher part of the Lower Chalk. This view finds confirmation in the sections near Beer Head in Devon, where the whole division is reduced to a thickness of only 10 feet, and consists of two beds—the lowest comparable to Chloritic marl, as it contains green grains and phosphatic fossils; the upper a hard nodular, rocky chalk.

**Middle Chalk.**—Dr. Barrois was the first to establish this division in the Isle of Wight,[1] and to compare it with the French Turonien. It there consists of:—

| | Feet. |
|---|---|
| Soft chalk, with a layer of green-coated nodules at the base (? Chalk rock) | 8 |
| White chalk in thick beds, with a few flints—zone of *Terebratulina gracilis* | 120 |
| Hard chalk, with a band of hard yellowish nodular rock at the base—zone of *Inoc. labiatus* or *Rhynch. Cuvieri* | 60 |

[1] "Annal. Sciences Geol.," 1875.

The same zones are traceable through Dorsetshire with little change. In Devon, however, they are somewhat modified; the lower beds of hard yellowish gritty chalk are known as "Beer stone," and are 24 feet thick. The overlying beds contain numerous lines of flints, and are about 75 feet thick; at the top is a layer of hard nodules which seem to represent the Chalk rock. Here, then, the Middle Chalk is only 100 feet thick. In Wiltshire the beds are similar to those of the Isle of Wight, but not so thick.

**Upper Chalk.**—In the Isle of Wight the composition of this division is similar to that of the Kentish Upper Chalk, but includes higher beds than are there found.

The zone of *Micraster cortestudinarium* has a thin layer of black clay at the base, which forms a clear line of division between the Middle and Lower Chalk. Above is rough yellowish chalk, consisting of hard nodular lumps embedded in a softer matrix. *Echinoderms* are very common, especially *Micrasters*, *Ananchytes ovatus*, and *Holaster planus*. Its thickness is about 60 feet.

The mass of the overlying chalk with flints is placed by Dr. Barrois in the zone of *Micraster coranguinum*, but he then included the Margate chalk with *Marsupites* in that zone,[1] and he indicates a band of flintless chalk in the position of the latter zone at Arreton Down. Thickness perhaps 500 feet.

The highest chalk of the Isle of Wight is soft and white, with large flint nodules; *Belemnitella mucronata* and *Magas pumilus* are common fossils. This zone is over 200 feet thick.

These zones have been traced through Dorsetshire by Dr. Barrois, who found them all developed near Dorchester, but thinner than in the Isle of Wight. At Beer Head in Devon, the zone of *M. cortestudinarium* is not more than 30 feet thick, and is overlain by a portion of the *coranguinum* zone (30 feet seen).

In Wiltshire there is about 300 feet of Upper Chalk.

[1] "Annal. Sciences Geol.," 1875; see also "Recherches sur le Terr. Cret. Supérieur," p. 107.

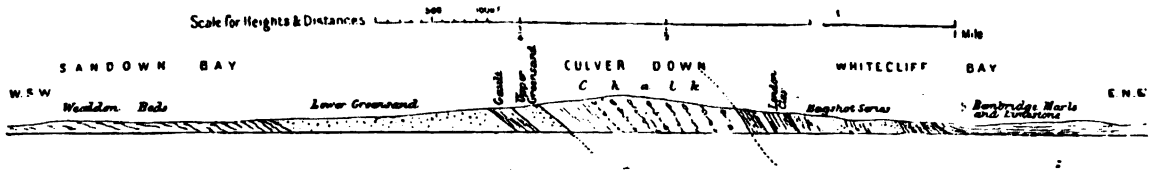



Fig. 103. Section along the eastern coast of the Isle of Wight (Topley).
Reproduced by permission from "Proc. Geol. Assoc."

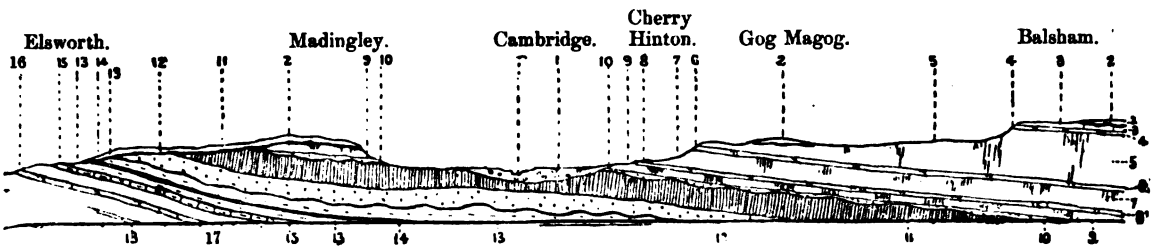



Fig. 104. Section through part of Cambridgeshire. Distance 20 miles.
Reduced from the Geol. Survey section, and reproduced by permission from "Proc. Geol. Assoc."

1. River Gravel.
2. Boulder Clay.
3. Upper Chalk.
4. Chalk Rock.
5. Middle Chalk.
6. Melbourn Rock.
7. Grey Chalk.
8. Totternhoe Stone.
9. Chalk Marl.
10. Cambridge Greensand.
11. Gault.
12. Lower Greensand.
13. Kimeridge Clay, with
14. Knapwell Limestone.
15. ? Equivalent of Coral Rag.
16. Oxford Clay.
17. } Elsworth and St. Neot's Limestones
18. } in the Oxford Clay.

### 3. *Midland District.*

As the beds of the Upper Cretaceous series are traced northward from the Vale of Pewsey through the counties of Berks, Oxon, Bucks, Beds, and Cambs, important changes take place in the lower part of the series, though the zonal divisions of the Chalk above are maintained with little alteration. The escarpment of the Chalk forms a prominent physical feature, forming the front of the Marlborough and Lambourn Downs on the west side of the Thames Valley and the Chiltern Hills on the eastern side. The bold outlines of the frontal spurs and ridges of these hills is doubtless due to the hardness of the Chalk rock and the nodular chalk above it, as these beds invariably form the capping of such ridges.

**Gault and Upper Greensand.**—The Gault forms a continuous band of low-lying clay land throughout the district, and in Bucks, Bedford, and Cambridge it occupies the greater part of the plain which intervenes between the escarpments of the Chalk and the Lower Greensand. Little is yet known of its composition, except in the counties just mentioned. It appears to attain its greatest thickness in Bucks, where the following horizons can be recognized.[1]

| | | |
|---|---|---|
| 5. Bluish micaceous clays | Upper Gault. 80 feet. | |
| 4. Pale grey calcareous clay. | | |
| 3. Layer of phosphate nodules mixed with glauconite grains | | |
| 2. Stiff dark blue clays. | Lower Gault. 160 feet. | |
| 1. Slate-coloured clay, with layers of nodules near the base | | |

The fossils in No. 1 are a mixture of species elsewhere characterizing Upper and Lower Gault, *Am. rostratus* and *cristatus* occurring with *Am. lautus* and *interruptus*, *Inoceramus sulcatus* with *I. concentricus*; *Belemnites minimus* is very abundant. In the upper nodule bed, however, the fossils are all of Upper Gault species, viz. *Am. rostratus*, *A. splendens*, *A. raulinianus*, *Terebratula biplicata*, and *Avicula gryphæoides*—the same *Avicula* is the principal fossil in the uppermost clays.

[1] *Vide* Jukes Browne in "Quart. Journ. Geol. Soc.," vol. xxxi. p. 265, and "Mems. Geol. Survey, Explan. of Sh. 46."

Traced to the north-east, the Lower Gault thickens to 200 feet, but the Upper Gault is cut out gradually by erosion, and the fossils of the nodule bed (No. 3) are found washed out and *remaniés* at the base of the Chalk marl in Bedford and Cambridge. In Cambridge, too, the Lower Gault becomes rapidly thinner, and finally dies out near Gayton in West Norfolk; this disappearance however may be partly due to the overlap of the Chalk marl.

The Upper Greensand in Wilts and Berks consists of two members—(1) hard calcareous firestone, with *Holaster lævis*, 6 feet; (2) soft green glauconitic sand (30 feet), with few fossils except at the top, where it passes into Chalk marl. In Oxford and Bucks the green sands gradually thin out, and are lost altogether near Tring; the firestone is absent, and the mass of the rock mapped as Upper Greensand by the Geological Survey consists of a tough, grey, micaceous marlstone or malm. This calcareous stone contains few fossils but *Avicula gryphæoides* and *Am. auritus*; it passes down into Upper Gault, and a revision of this area will probably result in its being classed with the Gault rather than with the true Upper Greensand.

**Lower Chalk.**—The following is the constitution of this division all along its outcrop north-east of the Thames Valley:—

| | Feet. |
|---|---|
| 5. Soft grey shaly marl, inclosing a band of hard white chalk; *Belemnitella plena* . . . . . | 3 to 5 |
| 4. Tough blocky chalk, without distinct bedding; *Holaster subglobosus*, *Am. rotomagensis* . . . . . | 60 to 80 |
| 3. Totternhoe stone, hard grey sandy chalk; *Rhynch. mantelliana*, *Lima echinata*, *Kingena lima*, *Pecten fissicosta*, &c., &c. . . . . | 2 to 20 |
| 2. Soft marls, with occasional layers of hard marly rock in Oxford and Bucks; *Am. varians*, *Rhynch. Martini*, *Inoceramus latus* . . . . . | 60 to 80 |
| 1. Marl with green grains, passing into the nodule bed known as Cambridge Greensand . . . . . | 1 to 2 |

The Cambridge Greensand commences near Barton-le-Clay (north of Luton), to which locality the nodule bed in the Gault has been traced, and there can be little doubt that all the nodules and fossils preserved in phosphate which occur in the Cambridge Greensand have been derived from the erosion and destruction of the Upper Gault in

that area. This derived fauna comprises some 210 species of Invertebrata, but about eighty of these have not yet been recognized elsewhere in England; out of the remaining 130 no less than 114 occur in the Gault of Folkestone, between eighty and ninety (including nearly all the commoner fossils) occurring in the Upper Gault; the commonest Ammonites are *Am. rostratus*, and the varieties of *Am. auritus*, *Avicula gryphæoides*, *Terebratula biplicata*, and *Plicatula pectenoides* are also abundant; *Rhynchonella sulcata*, so common at Cambridge, has not yet been recorded from the Gault in England.

The Vertebrate fauna of the Cambridge Greensand is very remarkable, the remains of many species of Ichthyosaurs, Plesiosaurs, Dinosaurs, Chelonians, and Pterodactyles having been found, together with bones belonging to a bird (*Enaliornis*). Most of these bones have doubtless been washed out of the Gault, but some may be Chalk Marl forms, and it is difficult to separate them.

In the marly matrix of the Cambridge Greensand are *Vermicularia umbonata*, *Discoidea subucula*, *Micrabacia coronula*, *Rhynchonella lineolata*, *Kingena lima*, and *Terebratulina triangularis*, most of which occur also in the Chalk marl above.

Another speciality of this district is the Totternhoe stone, so named from a place near Dunstable, where it is 20 feet thick, and is quarried for building purposes. It varies rapidly, however, in thickness, and is sometimes represented by two beds of sandy stone, with chalk marl between them. At its base there is usually a layer of green-coated phosphatic nodules, and small fragments of phosphate are common in the stone above.

This Totternhoe stone forms the base of the *Holaster subglobosus* zone, and that fossil is occasionally found in it, as are also *Am. rotomagensis* and *Am. cenomanensis*, though they are much more common in the chalk above. The *Hol. subglobosus* zone consists of grey chalk in the lower part, and whitish chalk in the upper part; its thickness appears to vary, as if it had suffered from contemporaneous erosion during the deposition of the shaly marl which overlies it.[1]

[1] See Hill and Jukes-Browne in "Quart. Journ. Geol. Soc.," vol. xlii. p. 216.

**Middle Chalk.**—The zones of this division exhibit the same lithological and palæontological characters as in the areas previously described. Its thickness is about 220 feet.

The Melbourn rock at the base is about ten feet thick, and consists of very hard nodular rock, which is locally known as "rag." It passes up into hard chalk with *Inoceramus mytiloides* and *Rhynchonella Cuvieri*.

The central part consists of soft white chalk, with occasional nodules of flint and layers of grey marl. It contains *Galerites subrotundus*, *Spondylus spinosus*, and *Terebratulina gracilis*.

The highest portion holds *Holaster planus*, and is crowned by the hard yellowish rock which has been called "Chalk rock" by Mr. Whitaker. In Oxford and Bucks there are at least two beds of such rock, and it is the lowest of these which forms the top of the Middle Chalk. This lower rock always contains green-coated nodules and green glauconite grains, and in it *Ammonites prosperianus*, *Scaphites Geinitzi*, *Turbo gemmatus*, and many other Gasteropoda are found.

**Upper Chalk.**—Only the lower part of this division is accessible near the Chalk escarpment, for the higher beds are hidden by later deposits (Eocene and drift).

The glauconitic "chalk rock" above mentioned is succeeded by loose nodular chalk like that of Dover, and generally full of *Micraster cortestudinarium*; this is 15 or 20 feet thick, and is sometimes capped by a second bed of chalk rock, which, however, has no green grains. Above this is chalk with frequent lines of black flints, and occasional nodular beds for about 50 feet.

This is succeeded by chalk with both nodules and floors of flint, in which fossils are scarce, but which may be referred to the zone of *M. coranguinum*.

### 4. *Northern District.*

This district includes the northern part of Norfolk, Lincolnshire, and Yorkshire. The whole series has undergone considerable changes, both in its lithology and palæontology, before it reaches Lincolnshire, and as the connecting area in Norfolk has not yet been thoroughly examined, the cor-

relations which have been made between the Northern and Midland types may eventually require modification. The escarpment of the Chalk forms the western edge of the Lincolnshire and Yorkshire Wolds, and the manner in which its base passes transgressively over the Jurassic outcrops has been indicated on p. 334. In Yorkshire the strike of the beds changes from N.N.E. to north, and finally curves round to the west, and the escarpment runs along the south side of the Vale of Pickering to the coast between Speeton Gap and Flamborough Head.

**Red Chalk.**—The Gault, Upper Greensand, Chloritic marl, and Chalk marl are all absent in this district, and their place is taken in the Hunstanton cliffs by four feet of hard red and pink chalk. This band of red chalk has been referred to all and each of the absent stages by different authors, to the Gault by Mr. Wiltshire,[1] to the Upper Gault alone by Dr. Barrois,[2] to the Upper Greensand by Professor Seeley,[3] and to the Chalk marl by Mr. Whitaker,[4] but probably the supposition that it represents all of them is nearer the truth, in the sense that its materials were accumulated very slowly, over a tract of the sea-bottom, where for some reason or other no fine argillaceous or calcareous matter was deposited, though such deposits were being formed contemporaneously further south. This view is borne out by the fact that the Red Chalk is divisible into three distinct portions or beds, the lowest of which contains a majority of Gault fossils, and the uppermost contains only Chalk marl species, as below:—

3. Pink chalk, with *Inocerami*.
2. Reddish chalk, with many *Belemnites minimus*.
1. Brick-red chalk, with *Terebratula biplicata*, *Am. rostratus*, *Am. auritus*, *Cidaris Gaultina*.

A similar succession is found in Lincolnshire, where the thickness is about 10 feet, and the lower beds in both counties contain numerous small pebbles of quartz, but at Speeton in Yorkshire, where it rests on clays, such pebbles do not occur.

[1] "Quart. Journ. Geol. Soc.," vol. xxv. p. 185.
[2] "Recherches sur le Terr. Cret. Sup.," p. 157.
[3] "Ann. Mag. Nat. Hist.," Ser. 3, vol. vii. p. 233.
[4] "Proc. Norwich Geol. Soc.," part vii.

At Speeton, moreover, it is represented by a red marl some 30 feet thick, which is quite different from the hard gritty rock of Hunstanton. No *Ammonites* have been found in it, and its fossils appear to be those which characterize the two upper beds of the Hunstanton rock.

**Lower Chalk.**—In Lincolnshire this consists of the following beds, as seen near Louth :—

| | Feet. |
|---|---|
| 6. Band of variegated marl, grey, red, and purple | 2½ |
| 5. Hard white chalk, with thin seam of red marl below | 2 |
| 4. Hard greyish chalk, with two bands of pink chalk from 5 to 7 feet thick | 32 |
| 3. Hard grey chalk, rough and nodular | 30 |
| 2. Hard grey gritty stone, full of fragments of *Inoceramus* | 5 |
| 1. Hard nodular chalk, with yellow and pink stains | 1½ |
| | 73 |

Bed 1 forms a kind of passage into the red rock below; it often exhibits the branching structureless masses which are known as *Spongia paradoxica*. The hard grey stone (2) and the beds just above it contain many of the fossils which are found in the Totternhoe stone; *Holaster subglobosus* and *Discoidea cylindrica* are common throughout 3, and occur also in 4, and it is clear that these three members (2, 3, 4) represent the zone of *Holaster subglobosus*. Nos. 5 and 6 probably correspond to the marl with *Belemnitella plena*, though that fossil has not yet been found in Lincolnshire.

The lower half of the above section can be seen also in the Hunstanton cliffs. At Speeton the section is rather different, and is obscured by talus, so that observers differ with regard to the real sequence of the beds seen.

**Middle Chalk.**—There is no locality yet known where the whole of this can be examined, but the Melbourn rock has recently been found in Norfolk, succeeded by the zone of *Rh. Cuvieri*, which is overlain by a considerable thickness of white chalk with *Galerites subrotundus*; the highest beds of the division have not yet been examined. In Lincolnshire the lower beds are easily studied near Louth, where above the variegated marl we find 15 feet of hard whitish and yellowish chalk in thick beds with partings of grey shale; *Inoceramus mytiloides* is here abundant, and this

quarries in chalk which may lie
The greater part of this (60 to 7
contains *Terebratulina gracilis* a
so there can be no doubt of its T
there is chalk with frequent ba
Barrois found *Holaster planus*.
cliffs of North Sea near Flambo
so hard that fossils cannot be ext

**Upper Chalk.**—This divisio
and Yorkshire; but in neither c
of the Chalk rock been discovere
yet been clearly defined; neither
*Micrasters* be separated.

Chalk, with *Micraster corangu*
indicated by Dr. Barrois (op. cit.,
and Burnham Overy, while at We
chalk with very few flints, which l
zone; the Norwich chalk belongs
*tella mucronata*, and has long b
which include *B. mucronata*, *Ter*
*octoplicata*, *Magas pumilus*, *Pect*
*laxa*, and many others. A well
through 1,050 feet of chalk with fl
and 102 of hard chalk below. At
beds occur, which are probably the
are characterized by *Ostrea lunata*,
*Trochosmilia cornucopiæ*, and cont

Barrois and Mr. J. F. Blake, whose accounts agree very closely; they describe it as broadly divisible into two portions:—

2. Zone of *Marsupites*—soft white chalk without flints; *Marsupites ornatus*, *M. lævigatus*, *Belemnites vera*, and *Bel. quadrata*, *Scaphites binodosus*, *Sc. compressus*, *Hamites cylindricus*.
1. Zone of *Micrasters*—white chalk with layers of flint.

The chalk with *Micrasters* represents the two southern zones of *M. cortestudinarium* and *M. coranguinum*, both of which occur in it, together with *Ananchytes ovatus* and *Terebratula carnea*. The chalk with *Marsupites* is best seen at Dane's Dyke, south of Flamborough Head, where it is full of the characteristic fossils. It is divisible into a lower portion in which *Marsupites* abound, but sponges are rare, and an upper portion in which *Marsupites* are less common and sponges are very abundant, *Jerea*, *Ventriculites*, *Capulospongia*, *Verrucospongia*, and *Cœloptychium* being the principal genera.

Dr. Barrois points out the close correspondence between the zone of *Marsupites* in Yorkshire and the zone of *Belemnitella quadrata* in Germany, where the same fossils occur.

The Norwich chalk or zone of *Bel. mucronata* does not appear to be present, or at any rate exposed to view.

### 5. *Ireland.*

Upper Cretaceous rocks appear nearly everywhere round the edge of the great basaltic plateau of Antrim, Tyrone, and Londonderry, and we may therefore safely infer that they underlie the greater portion of it. It is also clear that they once extended much farther westward than the present edge of that plateau, as is proved by a small outlier near Draperstown. They usually rest on a planed down surface of Liassic or Triassic rocks, but sometimes overstep the limits of these, as in north-east Antrim, and rest upon the Palæozoic rocks (see fig. 105).

The Irish series is divisible into two groups of different

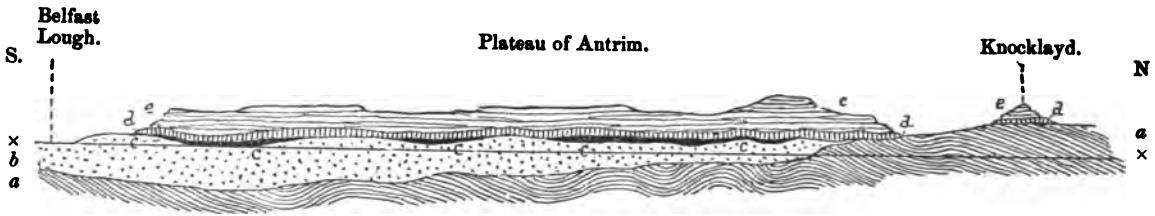



Fig. 105. Diagrammatic Section across the Plateau of Antrim, showing the relation of the Neozoic to the Palæozoic Rocks. Distance about 40 miles.

*e.* Tertiary Basaltic Series.
*d.* Cretaceous Series.
*c.* Lias and Rhætic Beds.
*b.* Triassic Marls and Sandstones.
*a.* Palæozoic Rocks.
× × Sea-level.

The author is indebted to Mr. F. W. Egan of the Geological Survey of Ireland for correcting and improving the original sketch of this section.

lithological character: (1) the Hibernian Greensand; (2) the Chalk or White Limestone. The first is similar in general aspect to our Upper Greensand, but represents the whole of the Lower Chalk and perhaps part of the Middle; the upper group rests on an eroded surface of the Lower, and is equivalent to the higher part of the Upper Chalk or Senonien.

The most complete section, at Colin Glen near Belfast, is given below:—

| | | Feet. |
|---|---|---|
| White Limestone. | 6. Hard white chalk with many flints; *Belemnitella mucronata, Ananchytes ovatus, Rhync. octoplicata* | 30 |
| | 5. Hard white chalk with few flints, *Belemnitella mucronata, Marsupites ornatus, Galerites conicus* | 2½ |
| | 4. Hard chalk with green grains and quartz pebbles; *Galerites conicus, Micraster coranguinum*, and *Ventriculites* | 2½ |
| Hibernian Greensand. | 3. Green sands and sandstones; *Ostrea columba, Galerites subrotundus, Rhynchonella Cuvieri, R. limbata, Cidaris subvesiculosus, Orbitolina concava* | 17 |
| | 2. Yellowish calcareous sandstones, *Ostrea carinata, Holaster subglobosus, Discoidea subuculus, Micrabacia coronula* | 34 |
| | 1. Dark green glauconitic sands with phosphate nodules; *Pecten asper, Ostr. conica, Am. varians*, and *Bel. ultimus* | 9 |

There seems little doubt that bed No. 1 belongs to the zone of *Pecten asper;* No. 2 represents the Chalk marl, and perhaps part of the overlying zone of *Holaster subglobosus.* The correlation of No. 3 is more difficult; by position it should belong to the upper part of the Lower Chalk, and Professor Tate regards it as such. Dr. Barrois considers the fossils to be more of a Turonien assemblage, but I do not think it can be placed higher than the zones of *Rhynch. Cuvieri* and *Terebratulina gracilis,* and there is nothing to represent the zone of *Holaster planus* or the Chalk rock; No. 4 appears to be the exceedingly reduced representative of the chalk with *Micrasters* which is so thick in England; Nos. 5 and 6 may be correlated with the *Marsupite* and *Belemnitella* zones respectively.

In the north-east of the county (White Head and White

Park Bay) much more of the white chalk with *Bel. mucronata* is exposed, 90 feet being visible, according to Dr. Barrois.

### 6. *Scotland.*

Cretaceous rocks have only yet been discovered in one part of Scotland, namely, in the island of Mull, and in the district of Morvern on the adjacent mainland; as in Ireland they belong exclusively to the upper division of the system, and though they can be correlated generally with the Irish series, they exhibit a still more abnormal facies, and a more decided approach to littoral conditions.

The characters and relations of the Cretaceous beds can be ascertained best in Morvern (see fig. 67), along the shores of Loch Aline, and beneath the singular outlying masses of Beinn-y-Hun and Beinn-y-Hattan. The general succession here is given below:[1]—

| | Feet. |
|---|---|
| 4. Sandstones and white marls with plant remains (high Cretaceous or early Eocene) | 20 |
| 3. White indurated chalk with bands of flints, *Belemnitella mucronata*, and fragments of *Inoceramus;* some beds of glauconitic chalk at the base | 10 |
| 2. White sandstones without fossils, but containing a thin seam of coal | 30 to 100 |
| 1. Glauconite sands, passing sometimes into dark green argillaceous sand, sometimes into calcareous sandstone; *Pecten asper, P. orbicularis, Exogyra conica*, but *no* Ammonites found | 20 to 60 |

On comparing these beds with those of Antrim, we may safely regard No. 1 as equivalent to Nos. 1 and 2 of the Hibernian Greensand, but the absence of *Ammonites* and *Belemnites* in the Scotch beds is noteworthy as indicating the shallowness of the water in which they were deposited.

The overlying white sandstones (No. 2) would appear to be homotaxial with the zone of *Ostrea columba* in Ireland, whatever the precise age of that may be. Above it there is a palæontological break, though apparently no unconformity, and the hard white chalk corresponds closely to that of Ireland, except that there is no sign of the *Micraster* zone at its base.

[1] J. W. Judd, "Quart. Journ. Geol. Soc.," vol. xxxiv. p. 729.

As shown in fig. 67, the Greensands rest sometimes on the Lias, and sometimes on the Trias, and sometimes overlap both on to the metamorphic rocks which support the whole Secondary series. Occasionally, as at Gribun, in Mull, the base of the Greensand consists of pebble beds derived from the waste of the Triassic rocks.

### 7. *Upper Cretaceous Series of France.*

The Cretaceous rocks of the Paris basin closely resemble those of England, and were evidently deposited in the same life-province, but those of the west and south of France belong to a different area of deposition, and exhibit quite a different type. Space will not allow of my describing both, and the following *résumé* relates only to the northern districts, for which the chief authorities are Professor Hébert and Dr. Barrois.

**Albien.**—French geologists attach the zone of *Ammonites mammillaris* to this division rather than to the Aptien. Above it are clays like those of our Lower Gault, and Barrois divides these into two zones, (1) of *Am. interruptus*, (2) of *Epiaster Ricordeanus*.

**Cenomanien.**—The equivalent of our Upper Gault (the zone of *Am. inflatus*) is placed at the base of this stage (see p. 397), which thus comprises the following zones:—

5. Marl, with *Belemnitella plena*.
4. Chalk, with *Holaster subglobosus*.
3. Marl, with *Am. varians* and *Tur. costatus*.
2. Greensand, with *Pecten asper*.
1. Clay or "gaize," with *Am. inflatus*.

**Turonien.**—The constitution of this stage is similar to that of the English Middle Chalk, and Dr. Barrois found that the zones established in the Turonien of France, viz., (1) zone of *Inoceramus labiatus* (= *I. mytiloides*), (2) zone of *Terebratulina gracilis*, (3) zone of *Holaster planus*, were the same on both sides of the English Channel. Another zone (characterized by *Micraster brevis*) sometimes occurs above that of *H. planus*, and Dr. Barrois attaches this to the Turonien, but Professor Hébert places it at the base of the

Senonien. In the Ardennes region the *H. planus* zone occurs in the form of Chalk rock.

**Senonien.**—If the *Micraster brevis* zone is regarded as Turonien, the Senonien will comprise the following zones:—

| | |
|---|---|
| Assise à Belemnitelles. | z. à *Belemnitella mucronata.* |
| | z. à *Belemnitella quadrata.* |
| Assise à Micrasters. | z. à *Marsupites.* |
| | z. à *Micraster coranguinum.* |
| | z. à *Micraster cortestudinarium.* |

**Danien.**—This, in France, consists of two well-marked subdivisions:—

2. Pisolitic limestone.
1. Chalk, with *Baculites.*

The Pisolitic limestone is of a yellowish colour, and rests on an eroded surface of the underlying chalk, and the majority of its fossils are more allied to Eocene than to Cretaceous species; the only Cephalopod is *Nautilus Danicus.* In Belgium the grey chalk of Ciply, containing *Baculites Faujasi, Belemnitella mucronatus, Radiolites ciplyanus,* &c., rests unconformably upon the Senonien, and is surmounted by the yellow limestone of Maestricht, which contains *Ostrea lunata, Hemipneustes radiatus,* with species of *Voluta, Fasciolaria,* &c.

In Denmark this stage consists of (1) the chalk of Saltholm, (2) the yellow limestone of Faxoe; part of the latter is largely composed of corals, with which are many Gasteropods belonging to the genera *Cyprœa, Oliva, Mitra, Cerithium, Fusus, Trochus,* &c., and Cephalopoda including *Baculites Faujasi* and *Nautilus Danicus.*

The Danien beds everywhere occupy more limited areas than the mass of the underlying chalk, probably in consequence of their having been deposited during upheaval over limited tracts of the sea-bottom.

## PHYSICAL GEOGRAPHY.

**Lower Cretaceous Time.**—We have seen that at the close of the Jurassic period the area of deposition was limited to a region south of the latitude of London and the

Vale of Wardour. Everywhere to the north of this line there is a gap and unconformity between the Jurassic and Cretaceous rocks; and we may conclude that the greater part of the British area was then in the condition of dry land. The areas occupied by the Palæozoic rocks formed hilly and mountainous ground as they do now, and between these districts over the midland counties of England, and over the space now occupied by the Irish Sea, and thence by the North Channel far out into the Atlantic, spread a fertile lowland district formed of the newly emerged Jurassic strata.

It was only in the southern part of our area that deposition was continuous throughout the interval which elsewhere separates the Jurassic and Cretaceous systems; and here an extensive series of freshwater deposits was in process of formation, a series which is generally spoken of as the delta of a great river, and is usually compared with the deltas of rivers like the Nile and Mississippi, which empty themselves into the sea. It is by no means certain however that the area occupied by the Wealden beds was the head of a marine gulf or bay, for it is difficult to see in which direction it could have communicated with the open sea; the absence of Lower Cretaceous deposits over Belgium and the north of France points to the existence of land on the east, and there is no reason to suppose that the Palæozoic areas of Devon and Cornwall were then separated from those of north-western France by anything deeper than the valley of a large river. Moreover, the delta of a large river entering the sea is generally, if not invariably, composed of alternating marine, estuarine, and freshwater beds, whereas the Wealden series is entirely of freshwater origin; hence many have regarded the formation as a purely lacustrine one.[1]

Whether the Wealden delta was the result of more than one river, and whether the principal river came from the east or the west, are also matters of doubt. It is probable, however, that one or more rivers did drain the continental land which lay to the west of Cornwall and Devon. It has

[1] See S. V. Wood, in "Phil. Mag.," ser. 4, vol. xxv. p. 268; C. J. A. Meyer, "Quart. Journ. Geol. Soc.," vol. xxviii. p. 243; and Topley, "Geology of the Weald, Mem. Geol. Survey," p. 324.

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posited (see p. 391), and the sea of which it formed part stretched eastward into Hanover, but was probably entirely cut off from the Wealden lake by the sub-Cretaceous ridge of Belgium and eastern England.

Returning to the southern area, we find proof that it sank too rapidly for deposition to keep pace with subsidence, so that eventually the great delta was overflowed by the sea, and a marine fauna occupied the place of a freshwater one. The marine shells in the uppermost Wealden beds of the Isle of Wight show that the sea had already invaded the area of the delta, but the final change seems to have taken place rather suddenly, probably by a decided subsidence, so that a large part of the delta became the bottom of a shallow tidal sea and was invaded by a number of new marine molluscs; these were chiefly such as love to burrow in muddy bottoms (*Pinna*, *Panopœa*, &c.), and their shells now remain at the base of the Atherfield clay, embedded in the same vertical position which the animals took up when they burrowed into the soft mud. The subsequent varying conditions of the sea-bottom, according as sand or mud predominated, and the successive appearance of various kinds of molluscs in the Vectian beds, are excellently described by Professor Forbes.[1] Higher up the estuary, that is, to the westward, estuarine and freshwater conditions would of course prevail, and it is not surprising therefore to find such an interdigitation of marine and fluviatile deposits as the Punfield beds present. If the south-westerly continuation of these beds had not been destroyed, we might have been able to trace them into a region where the whole Lower Cretaceous series was of the freshwater Wealden type.

We can only deal, however, with the eastern part of the gulf, and with the gradual extension of this sea over the land to the north. It will be remembered that, while the lower members of the Lower Greensand are confined to the extreme south of England, and do not occur beneath the great diagonal escarpment of the Chalk, the upper members (Shanklin sands) are more or less continuous all across England from Dorset to Norfolk; and, further, that these

[1] "Quart. Journ. Geol. Soc.," vol. i. p. 192; quoted in Bristow's "Geology of the Isle of Wight, Mem. Geol. Surv.," p. 17.

sands everywhere exhibit signs of rapid accumulation under the influence of strong currents, while proofs of marine erosion are found in the frequent layers of phosphatic nodules derived from pre-existent strata. The explanation of these facts is doubtless to be found in the partial submergence of the barrier which separated the southern and northern seas—the ridge which extended from Belgium through the east and centre of England, and the consequent influx of a strong current through the passage thus established.

The width and height of this ridge must have been gradually diminished throughout the preceding period, partly by subsidence, and partly by the ceaseless erosion of the sea—the waves of the Vectian sea were constantly encroaching upon its southern coast, while those of the Speetonian sea were making similar inroads upon its northern coast—till at length these two seas effected a junction across the lowest portion of the barrier, which seems to have been a tract between our modern counties of Berkshire and Cambridgeshire. The communication thus established remained, however, for some time in the condition of a strait or channel, through which ran a strong current from the north, as evidenced by the prevalent southerly dip of the obliquely-laminated sands of Beds and Bucks (see p. 390). The entire absence of Lower Greensand in the borings below London and the eastern counties leads us to conclude that this portion of the barrier still remained above water until the further submergence which ushered in the clays of the Gault.

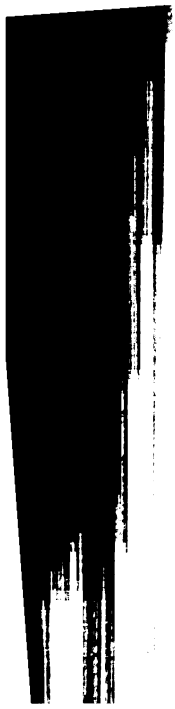
As to the width of what may be called the "western channel" we have no direct evidence, but the frequent overlap of the Lower Greensand by the Gault favours the supposition that the former never extended much beyond its present line of outcrop, and that the western coast of the channel consisted of the Upper Jurassic rocks; the freshwater beds of Oxfordshire are a further proof of the close proximity of land, and may be regarded as indicating the existence of a river which traversed the western lowlands, and may have had its rise in the mountains of Wales.

The total absence of any Lower Cretaceous rocks in Ireland or North Britain may be taken as evidence that

terrestrial conditions prevailed all over the western and northern part of our area; the modern mountains of Scotland and Ireland are but the ruined remnants of lofty ranges, which must then have towered to three or four times their present height above the sea, and from these mountain chains there must have flowed a thousand rapid streams, which becoming confluent in the plains produced the mighty river that emptied itself into the Wealden lake.

**Upper Cretaceous Time.**—We have now to chronicle the phases of the great subsidence which commenced at the epoch of the Gault, and continued throughout the remainder of the Cretaceous period, until a thickness of some 1,300 feet of sediment had been accumulated over the Lower Greensand. The thickness of the Upper Cretaceous sediments, however, as compared with those of the lower division, is no criterion of the relative duration of the two eras, for the coarser sediments of the earlier portion of the period must have been deposited far more rapidly than the fine materials of the later era. Some idea of the time occupied in the formation of the Chalk may be gained if we remember that the accumulation of the Atlantic ooze—the modern analogue of the Chalk—is a process so slow, that it is doubtful whether a foot's thickness of it is deposited in a century; at this rate 1,000 feet of chalk would require 100,000 years for its formation, and if we assume that chalk was accumulated twice as rapidly as the Atlantic ooze is supposed to be, the figures (50,000 years) still represent an enormous length of time.

The first result of the great subsidence was the submergence of the promontory which existed on the site of our eastern counties, and the outspread of the Gault muds over the whole of south-eastern England; at the same time the western shore of the Cretaceous sea was carried back to Devonshire, and doubtless also to the borders of Wales, though subsequent detrition has destroyed all evidence of the shore-line north of Devon. From the present disposition of the Cretaceous strata, however, we can hardly avoid the conclusion that the whole of central England, and, indeed, the whole of the great lowland area described on p. 425, was once more converted into a sea-bottom, on which sandy and glauconitic deposits were laid



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by an ocean which seems to have had a wide latitudinal extension, and may have been continuous from the southern part of North America, across the Atlantic, and through Europe into Asia. If this was the general trend and extent of the Cretaceous ocean, we may reasonably suppose the larger land areas of that period to have had a similar trend, at any rate in the northern hemisphere, and to have spread from east to west rather than from north to south like our present continents. It is probable, therefore, as Professor Prestwich suggested,[1] that a great northern continent stretched across what is now the shallower part of the North Atlantic Ocean, between Norway and Greenland, forming a barrier which excluded the colder waters of the Arctic seas, and allowed the Cretaceous ocean to have the full benefit of the warmer currents from the south.

In the pisolitic limestones of Belgium and Denmark we have proof that this long continued period of submergence had come to an end, and that a reverse movement had commenced, which ultimately led to the expulsion of the Cretaceous fauna from the European area, and the introduction of a very different shallow-water fauna, namely, that of the Eocene seas.

[1] "Pres. Address to the Geol. Soc., 1871," p. lxviii.

# CHAPTER XI.

## Tertiary or Cænozoic Time.

### Hantonian System.

As explained on page 36, the series into which Tertiary strata are usually grouped cannot be regarded as systems of equivalent palæontological value to those of older date, but the lower two of these series taken together, namely, the Eocene and the Oligocene, may be regarded as forming a system for which the name *Hantonian* has been proposed.

Both Eocene and Oligocene are subdivided into Lower, Middle, and Upper groups, and representatives of all these except of the Upper Oligocene are found in Britain.

#### *Range and Relation to Rocks below.*

We cannot doubt that during the elevation which took place at the close of the Cretaceous period, deposits were formed round the flanks of the mountain districts as they rose above the waves,—deposits which would be intermediate in age between the highest chalk and the lowest of the British Eocenes, but of such beds not a scrap remains, unless it be the marls which intervene between the Chalk and the Basalts of Western Scotland.

The lowest Eocene beds of England rest directly upon the Upper Chalk, which doubtless suffered a certain amount of erosion before they were deposited; but there is no evidence that the amount of chalk removed at that time was very large, for the hollows and pipes which sometimes

occur in the chalk beneath the Lower Eocenes appear to have been formed by the percolation of water subsequently to the deposition of the latter. The two geologists who are best acquainted with the Lower Eocenes, viz., Prestwich and Whitaker, agree in thinking that the magnitude of the stratigraphical break has been exaggerated. To this point further reference is made below.

The movements which have regulated the geographical disposition of the British Cretaceous rocks affect the Hantonian strata also, so that the latter come to occupy two distinct synclinal areas in the south-east of England, these areas being separated by the prolongation of the anticlinal axes of the Weald, and being known respectively as the London Basin and the Hampshire Basin.

A glance at any geological map will show the extent of the Hantonian beds in these two areas. The London Basin extends from Hungerford, in Berks, to Reculvers, in Kent, and its northern boundary passes from Reading through Bucks, Essex, and Suffolk, to north of Yarmouth, in Norfolk. Its greatest width, along the east coast, is about 90 miles, its length about 120; but this is less than half its original extent, the rest of the basin being concealed by the waters of the North Sea. The Hampshire Basin is much smaller, and lies in a trough between the anticlinal axis of Winchester on the north, and the monoclinal of Purbeck and the Isle of Wight on the south, and its extreme width is, therefore, only 25 miles, while its length from Dorchester to near Worthing, in Sussex, is about 90 miles, with an outlier at Newhaven nearly 20 miles further east.

To the west a small outlying tract of Eocene occurs in Devon near Bovey Tracey.

In Ireland freshwater beds of Eocene age are interstratified with the great sheets of basaltic lava which cover so large an area in Antrim and Derry. In Scotland a similar set of lavas, also with intercalated freshwater beds, attains a great thickness in the islands of the inner Hebrides (Mull, Skye, &c.)

The Oligocene beds are confined to the Hampshire basin; they occupy the northern part of the Isle of Wight, and a small area in Hampshire, and do not appear ever to have extended much farther northward.

In dealing with the deposits of this system we shall, as heretofore, enumerate the principal fossils and describe the stratigraphy of each series separately.

## 1. Eocene Series.

The labours of Prestwich, Forbes, Whitaker, and others have made us acquainted with the general succession of Eocene strata, but their classification, which is adopted by the Geological Survey, includes the beds now separated as Oligocene. The recognition of the Oligocene in Britain as a distinct series has necessitated a new grouping, and it must therefore be remembered that the Eocene as now defined and limited is only the Lower and Middle Eocene of the Geological Survey and of the older geologists. The following are the divisions of the Eocene series now recognized, with their maximum thickness in the two basins:—

| | London Basin. | Feet. | Hampshire Basin. | Feet. |
|---|---|---|---|---|
| 3. | Upper Bagshot . . | 150 | Barton Sands . . | 200? |
| | | | Barton Clay . . . | 300 |
| 2. | Middle Bagshot . . | 80 | Bracklesham and Bournemouth Beds | 530 |
| | Lower Bagshot . . | 150 | Lower Bagshot Sands | 250 |
| 1. | London Clay . . | 480 | London Clay . . . | 300 |
| | Lower London Tertiaries . . . . | 180 | Plastic Clay or Reading Beds . . . . | 160 |

### *Life of the Period.*

The difference between the fauna of the Chalk and that of the Eocene is very great indeed, for only one species, and that is a Brachiopod (*Terebratula striata*), seems to have survived the change of conditions in Britain, and not only so, but the general aspect of the Eocene fauna is quite different from that of the Cretaceous. The great Reptiles of the Secondary rocks have disappeared, and with them the numerous Cephalopods which are so characteristic of the Cretaceous system—the Ammonites, Turrilites, Bacu-

lites, Scaphites, Hamites, Belemnites, and many others; vanished also are the Hippurites, Radiolites, and Inocerami of the Chalk, the deep sea Ventriculites, and many genera of Echinoderms. So great is the palæontological break that it was formerly supposed to indicate a very great stratigraphical break and the lapse of an immense period of time; to this idea even Mr. Etheridge, in his recent Manual, lends his authority, going so far as to say that "this hiatus doubtless represents one of the greatest breaks in the successive deposition or sedimentation of the British rocks, if not in the history of the eastern hemisphere."[1] The tendency of modern research, however, has certainly been to diminish the importance of this break, both from stratigraphical and palæontological points of view. Even so long ago as 1854 we find Professor Prestwich remarking, with judgment and caution, that, "in viewing the London Tertiaries as a group, and comparing them, as usual, directly with the underlying Chalk, it is to be observed that we are not comparing like terms of the two periods. That a great and essential difference existed between these periods must be admitted, but it is a question how far that difference is widened by the comparison being instituted between the deep and open sea deposits of the Chalk and the littoral, shallow-sea, and fluviatile deposits of the Tertiary period, instead of between strata deposited under like conditions during these two periods. . . . . Where more shallow-water conditions again prevailed during the later Cretaceous periods, as at the time of the deposition of the Calcaire pisolitique, the fauna which then flourished presents forms closely resembling those of the overlying Tertiary strata."[2]

We cannot, in fact, be surprised that the fossils of the Eocene should differ enormously from those of the Chalk, because the conditions under which the creatures lived were so utterly different, but a comparison between two such faunas cannot possibly afford trustworthy evidence with regard to the magnitude of the time-break between the two periods. As a matter of fact, there is far less difference

[1] Phillips' "Manual of Geology," 1885, p. 598.

[2] "Quart. Journ. Geol. Soc.," vol. x. p. 443; see also vol. xxvii. Pres. Address, p. 55.

between the fauna of the Chalk marl and that of the Eocene, than there is between the latter and that of the Chalk immediately below it, and the reason of this is obviously that the Chalk marl was deposited in comparatively shallow water. Lastly, it may be observed that a few links between the Cretaceous and Eocene faunas do exist, our London Clay containing Echinoderms belonging to five essentially Cretaceous genera, viz., *Hemiaster*, *Bourgeticrinus*, *Pentacrinus*, *Astropecten*, and *Goniaster*. We have already seen that the actual evidence of unconformity between the Chalk and Eocene has been exaggerated, and it is highly probable that future discoveries will entirely bridge over the gap between the Secondary and Tertiary deposits even in the European area. In Egypt and Syria there appears to be a complete passage from one to the other, and the same is the case in North America.

The following are some of the genera which now make their appearance in Britain, though a few of the Gasteropods occur in the highest Cretaceous rocks of the continent:—

*Protozoa.*—Alveolites, Nummulites, Triloculina.

*Actinozoa.*—Balanophyllia, Dendrophyllia, Madrepora, Oculina, Solenastrea, Turbinolia.

*Echinodermata.*—Spatangus.

*Crustacea.*—Dromilites, Xanthopsis.

*Lamellibranchs.*—Diplodonta, Glycimeris.

*Gasteropoda.*—Ancillaria, Cancellaria, Conus, Cypræa, Marginella, Murex, Typhis, Oliva, Pleurotoma, Triton, Voluta.

*Cephalopoda.*—Aturia, Beloptera, Belosepia.

*Fish.*—Many Cycloids and Ctenoids.

*Reptiles.*—Alligator, Crocodilus, Lacerta, Palæophis.

*Aves.*—Odontopteryx, Dasornis, Halcyornis, Lithornis, Argillornis.

*Mammalia.*—Coryphodon, Lophiodon, Hyracotherium, Pliolophus, Palæotherium, Paloplotherium, Didelphys.

Of the above genera the most important and interesting from a biological point of view are the Birds and the Mammals. The *Odontopteryx* was a large fish-eating bird, possessing strong jaws armed with teeth, and having general affinities with the Pterodactyles of the Mesozoic periods; it belongs to an order which appeared somewhat earlier in

America. *Dasornis* was also a large bird, apparently resembling the extinct Moa of New Zealand. *Lithornis* was a vulture and *Halcyornis* a kingfisher.

Of the Mammals *Coryphodon* and *Lophiodon* resembled the recent tapir; *Palæotherium* and *Paloplotherium* were

Fig. 106. Alligator Hantoniensis, lower jaw (½). Barton Beds, Hordwell.

animals from which both the rhinoceros and the horse seem to have descended. *Hyracotherium* was a small animal combining characters now found in the peccary and the hyrax or Syrian coney; *Pliolophus* was also an ancestral form of hyrax. *Didelphys* was a true opossum, and in France the

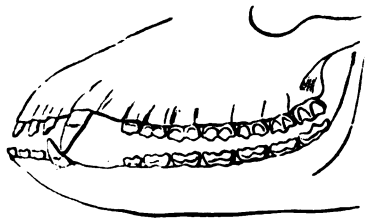


Fig. 107. Palæotherium magnum, jaws and teeth (⅛).

carnivorous Marsupials *Arctocyon*, *Pterodon*, and *Palæonictis* have been found. In France, too, the earliest hog-like animals occur, *Anchilophus* and *Heterobyus*, with a hornless form of deer (*Dichobune*). Professor Boyd Dawkins remarks,[1] "these animals constitute a small and insignificant

[1] "Early Man in Britain," p. 27.

fragment of a fauna, the ancestry of which is to be looked for in the Cretaceous age. They are of peculiar interest, because they show that at this time the carnivores were intermediate in character between the marsupials and the placental mammals."

The Eocene flora is marked by the incoming of *Dicotyledons*, especially such as belong to the order *Proteaceæ*, the members of which are now principally found in Australia.

In the Lower London Tertiaries, species of *Platanus*, *Populus*, *Alnus*, *Pinus*, *Laurus*, *Lygodium*, and *Glyptostrobus* have been identified by their leaves, principally from the Reading Beds.

In the London Clay of Sheppey, Messrs. Gardner and Ettingshausen have recently identified fruits of *Pinus*, *Callitris*, *Musa*, *Elais*, *Iriartea*, *Sequoia*, *Frenela*, *Podocarpus*, *Sabal*, *Nissa*, *Areca*, *Desmonais*, *Alnus*, and many varieties of leguminous seeds.

In the Lower Bagshot Sands, *Aralia* and *Podocarpus* occur, with *Quercus*, *Juglans*, *Laurus*, *Ficus*, *Grevillea*, *Dryandra*, *Cassia*, and *Cæsalpinia*, according to De la Harpe.

The Bournemouth Beds contain an abundant flora, which has been described by Mr. J. S. Gardner, who enumerates the following:—*Osmunda*, *Polypodium*, and *Acrostichum* (ferns); *Flabellaria*, *Sabal*, *Iriartea*, and *Phœnicites* (palms); *Populus* (?), *Ulmus* (?), *Salix*, *Laurus* (?), *Quercus* (?), *Daphnogene*, *Carpinus*, *Fagus* (?), *Godoya*, *Ficus*, *Stenocarpus*, and many *Proteaceæ*; *Rhamnus*, *Alnus*, *Celastrus*, *Eucalyptus*, and many *Leguminosæ*; *Cupressus*, *Cactus*, and *Araucaria*.

The following are the fossils characteristic of the marine and estuarine deposits of each subdivision:—

## Fossils of the Lower London Tertiaries

(Marine species).

*Lamellibranchs.*—Ostrea bellovacina, Cardium Laytoni, Corbula regulbiensis, Cyprina Morrisii, Thracia oblata, Glycimeris rutupiensis.

*Gasteropoda.*—Aporrhais Bowerbankii, Ap. triangulata, Natica subdepressa, Calyptrea trochiformis.

(Estuarine species.)

*Lamellibranchs.*—Cyrena cuneiformis, C. cordata, Ostrea bellovacina, and O. tenera.

Fig. 108. Leaves from the Lower Bagshot * and Bournemouth Beds. Borrowed from Mr. Gardner's paper in "Proc. Geol. Assoc.," 1877.

1. Corylus sp. (?).
2. Fagus sp. (?).
3. Laurus sp. (?).
4. Acer sp. (?) *
5. Aralia primigenia.*
6. Stenocarpus sp.
7. Dryandra acutiloba.*
8. Quercus sp. (?).

*Gasteropoda.*—Melania inquinata, Paludina lenta, Cerithium funatum, Melanopsis buccinoides, Hydrobia Parkinsoni, Neritina globulus.

## Fossils of the London Clay.

*Annelida.*—Ditrupa plana.

*Crustacea.*—Hoploparia Bellii, Xanthopsis tuberculata.

*Brachiopoda.*—Lingula tenuis, Terebratulina striatula.

*Lamellibranchs.*—Cryptodon angulatum, Pholadomya margaritacea, Pinna affinis, Modiola elegans, Panopæa intermedia, Pectunculus decussatus.

*Gasteropoda.*—Aporrhais Sowerbyi, Natica Hantoniensis, Voluta Wetherellii, V. nodosa, Phorus extensus, Pyrula Smithii.

*Cephalopoda.*—Nautilus imperialis, Aturia ziczac.

*Fish.*—Otodus obliquus, Cœlopoma Colei.

## Fossils of the Bracklesham Beds.

*Protozoa.*—Nummulites lævigatus, N. variolaria.

*Actinozoa.*—Litharæa Websteri.

*Lamellibranchs.*—Pecten corneus, Cardita planicosta, Solen obliquus, Sanguinolaria Hollowaysii, Chama squamosa, Pectunculus pulvinatus.

*Gasteropoda.*—Cypræa Coombii, Voluta cithara, Cerithium giganteum, Turritella imbricataria, T. sulcifera, Conus deperditus, Pleurotoma attenuata.

*Fish.*—Edaphodon Bucklandi, Myliobatis Edwardsii.

## Fossils of the Barton Beds.

*Protozoa.*—Nummulites planulatus.

*Lamellibranchs.*—Pecten reconditus, Cardita sulcata, Crassatella sulcata, Cardium turgidum, Pectunculus deletus, Sanguinolaria compressa.

*Gasteropoda.*—Rostellaria rimosa, R. ampla, Conus dormitor, Fusus longævus, F. pyrus, Murex asper, Typhis pungens, Voluta luctatrix, Phorus agglutinans, Pleurotoma colon, Oliva Branderi.

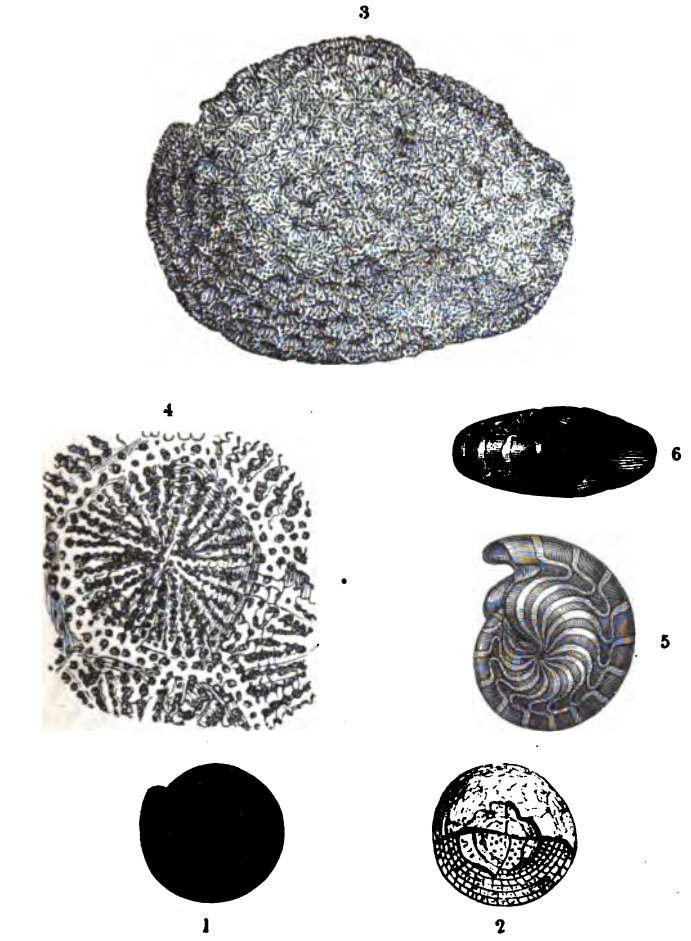



Fig. 109. Eocene Fossils.

1, 2. Nummulites lævigata. 3, 4. Litharæa Websteri
5, 6. Aturia ziczac. (3. Natural size; 4. Magnified portion).

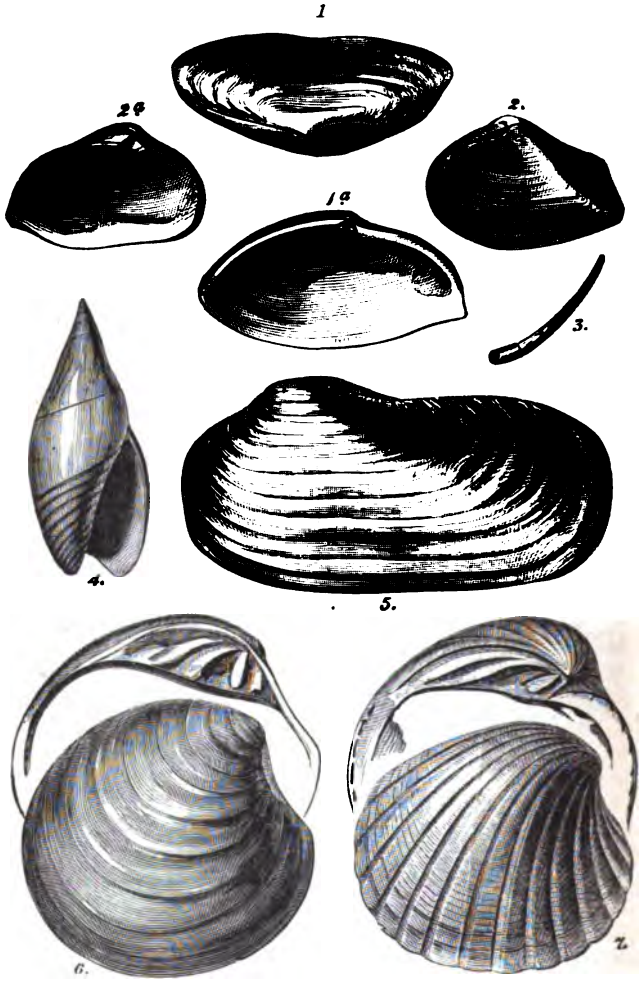



Fig. 110. Fossils of Eocene and Oligocene Beds.

1. Psammobia solida (Headon).
2. Corbula cuspidata (Headon).
3. Ditrupa plana (London Clay).
4. Ancillaria subulata (Headon).
5. Panopæa intermedia (London Clay).
6. Cytherea incrassata (Barton Clay and Headon Beds).
7. Cardita planicosta (Bracklesham).

*Stratigraphy.*

## 1. The London Basin.

**The Lower London Tertiaries**[1] is the name at present applied to the group of beds which lies between the Chalk and the London Clay; this group being divisible into three stages, which are respectively known as (1) Thanet Beds, (2) Woolwich and Reading Beds, (3) Oldhaven Beds.

*The Thanet Beds*, as their name implies, are well developed in the Isle of Thanet. They consist mainly of pale-coloured sands, the lowest part being always argillaceous and full of dark green glauconitic grains, while at the base, and resting on the Chalk, there is invariably a layer of *unworn* green-coated flints. These flints show no signs of attrition, and are believed to have been derived directly from the underlying chalk, not by mechanical erosion, but by chemical solution, through the agency of carbonated water percolating through the sands and dissolving the subjacent chalk, but leaving the insoluble flints behind, so that a layer of these nodules has gradually accumulated at the base of the sand, but was not there when the sands were originally deposited. This supposition is confirmed by the fact that no fossils occur in this basement bed, whereas if the flints had ever lain on a sea-bottom small oysters, serpulæ, &c., would certainly have fixed themselves on to such favourable surfaces for attachment.

In East Kent the greater part of this stage consists of greenish sandy marl (50 or 60 feet), overlain by sharp greenish-grey sand (30 to 40 feet), and both beds contain many fossils of marine species (see p. 438); westward, however, the upper sand entirely thins out, and the sandy marl passes into fine soft pale green or buff sand (argillaceous at the base), which in the west of Kent is about 50 feet thick; this type of the Thanet Beds is well exposed in the pits near Woolwich and Charlton, but contains no fossils. Thence they run by Crayford and Croydon to

[1] It is to be hoped that this name may eventually be replaced by a less awkward appellation.

Epsom, where they are only 15 feet thick, thinning out entirely near Ashstead.

The Thanet Beds thin northward as well as westward, for though well-sections at Chelmsford and Braintree show them to be about 30 feet thick, at their outcrop near Sudbury they are only 16 feet, and they thin out rapidly eastward and also to the south-west near Gestingthorpe.

*The Woolwich and Reading Beds* are a much more variable group, and exhibit three entirely different facies as they are traced from east to west:—(1) the marine type, consisting of grey sands with marine shells, is only found in East Kent; (2) the estuarine or Woolwich type occurs in West Kent and East Surrey, and consists of sands, clays, and loams, with estuarine and freshwater shells; (3) the plastic clay type of the western and northern tracts consists of unfossiliferous variegated plastic clays and bright-coloured sands, which are known as the Reading Beds.

In the coast section of Reculvers, Kent, the pale marine sands with sharks' teeth, *Corbula regulbiensis*, and other fossils are 25 feet thick. Near Milton, yellow and grey sands (possibly marine) underlie beds with estuarine shells, and the same is the case at Upnor, on the Medway, where the pit sections show:—

| | |
|---|---|
| Sands and dark clays, with *Cyrena*, &c. . . . | 20 feet. |
| Greenish-grey sands (? marine) . . . . . | 30 „ |

Westward the estuarine beds thicken to 50 feet near Lewisham, and are well seen both there and at Woolwich, where fossils are abundant, especially *Ostrea tenera*, *Cyrena cordata*, and *Melania inquinata*.

In West Kent, beds of mottled plastic clay begin to appear, and these increase westward through Surrey, the shell-bearing beds gradually dying out, till in Hants and Berks they consist entirely of such clays with beds of red, yellow, and white sand, and vary from 30 to 40 feet thick.

Along the northern lip of the basin through Herts and Essex they are of the same (Reading type), but include some pebble beds which are occasionally concreted into the kind of conglomerate known as "plum-pudding stone."

Near Sudbury the Reading Beds are very thin, but extend as far as Ipswich.

Mr. Whitaker remarks that where they rest on the Thanet sands the basement bed contains rolled flint pebbles, but that in the west, where they rest directly on the chalk, it contains only unworn green-coated flints.[1]

The plastic clays have yielded no fossils except the leaves of plants (see list on p. 438).

Overlying the estuarine beds of the Woolwich group in Surrey are pebbly sands and pebble beds, from 10 to 50 feet thick, which are termed the *Oldhaven or Blackheath Beds* by Mr. Whitaker, and are grouped by him as a third division of the Lower London Tertiaries. Their stratigraphical extent, however, is not great, and their palæontological importance is small, so that they hardly seem entitled to rank as a primary division.

In Kent their thickness is never more than 10 or 12 feet in those districts where the estuarine Woolwich Beds occur, but at Reculvers, where the latter are absent, there are 20 feet of marine sands (with *Cardium Laytoni*, *Cyprina Morrisii*, and *Aporrhais*); these are classed as Oldhaven Beds by Whitaker, but may represent the estuarine Woolwich Beds also. The probable relations of the beds composing the Woolwich group in Kent and Surrey are expressed in the accompanying diagram.

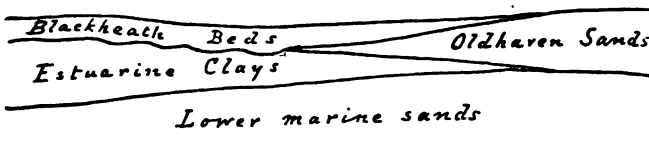



Fig. 111. Diagram to explain the composition of the Woolwich Beds.

The Blackheath pebble beds do not extend west of Croydon, and are not found along the northern edge of the London Basin. The pebbles composing them are all well-worn and rounded flints without any subangular pebbles such as occur on our shingle-beaches; hence Mr. Whitaker

[1] "Geology of the London Basin, Mem. Geol. Survey," vol. iv. p. 99.

concludes that they were not laid down in beaches, but were deposited by strong currents at some little distance from the shore, and his view is confirmed by the frequency of current bedding. The fossils they contain are sometimes of marine, and sometimes of estuarine species, as in the underlying beds.

**The London Clay** forms the second division of the London Tertiaries, and occupies broad areas both on the north and south side of the Thames Valley. It is of much more uniform composition than the lower group, the mass of it consisting of stiff bluish clay, with layers of septarian nodules. Its thickness near London is between 400 and 500 feet, but it thins gradually westward to about 270 at Wokingham, 50 near Newbury and Hungerford, and only 15 in the outlier of Great Bedwin, in Wilts, but this rapid thinning may be only apparent, and due in reality to an overlap of the Bagshot Sand.

The basement bed is of a different character to the rest, consisting of brown, grey, or greenish sand and sandy clay, in which are scattered many rolled flint-pebbles; these pebbles are always black, and sometimes have the remarkable peculiarity of falling into fragments when tapped by a hammer, for though to the eye they seem compact, they appear to be really traversed by a multitude of invisible cracks. This basement bed is generally from 6 to 12 feet thick, and it often contains fossils of which the chief are *Aporrhais Sowerbyi*, *Calyptrea trochiformis*, *Cytherea obliqua*, *Panopæa intermedia*, *Pectunculus brevirostris*, and *Ditrupa plana*.

The surface colour of the overlying mass of clay is generally brown, but this is due to the oxidation of the iron it contains by exposure to the weather; its normal tint in deep wells and borings is a bluish grey or slate colour.

Fossils are not common throughout the London Clay, but sometimes occur in great profusion, especially where bands of sandy clay occur (see list on p. 440). The cliffs of the Isle of Sheppey are noted for the fossils they yield, plant remains being here especially abundant and well preserved.

The London Clay and the underlying beds are usually grouped together as the Lower Eocene.

**Bagshot Beds or Middle Eocene.**—In the London Basin this series consists almost entirely of sand with occasional pebble beds; it has been divided into lower, middle, and upper stages.

The Lower Bagshot is composed of light grey sands, sometimes stained with iron or agglutinated into a ferruginous sandstone, and occasionally there are very thin layers of pipe-clay. Near the base a bed of rolled flint pebbles sometimes occurs, and these flints must either have been derived directly from the Chalk or from older Tertiary beds; in either case we must infer that the Bagshot Sands overlapped the London Clay. This overlap probably took place southward as well as westward. There are similar pebble beds in South Essex.

Mr. Irving has pointed out that the colour of these sands in deep wells is greenish, from an admixture of carbonaceous matter, which is destroyed by the action of oxygenated water when they are near the surface.

The Middle Bagshot is more varied, consisting of grey and brown laminated clays at the base, overlain by dark green clayey sand from 12 to 20 feet thick, and succeeded by a variable set of greenish sands with bands of clay, the total thickness varying from 40 to 80 feet. These beds have yielded a few fossils, *Turritella sulcifera*, *Cardita planicosta*, *C. acuticosta*, *Ostrea flabellula*, *Corbula striata*, *Nummulites lævigatus*, and many fish-teeth, *Otodus obliquus*, *Carcharodon megalotis*, &c.

The Upper Bagshot consists of white or light yellow sands irregularly bedded, and containing in the upper part blocks of white saccharine sandstone, which, when weathered out, are known as "grey-wethers;" these masses are sometimes 10 to 14 feet long, and 3 or 4 deep, and they often enclose flint pebbles. Organic remains are rare, but here and there are casts of shells, some of which have been identified as *Turritella sulcifera*, *Natica patula*, *Calyptrea trochiformis*, *Ostrea flabellula*, and *Nummulites planulatus*. These beds reach a thickness of 140 feet, and may have been thicker, for they are the highest beds in the London Basin.

The Bagshot Beds above described occupy a large tract in Berks, Hants, and Surrey, some 20 miles long, with a

maximum breadth of 10 or 12 miles; large outliers of the lower sands occur both to the west and east of this mass, and smaller ones in Middlesex and Essex. The middle division occurs as a mass in the broadest part of the tract, and according to the Geological Surveyors, the upper sands form small tracts over its surface (Chobham and Frimley ridges, &c.); Mr. Irving, however, has adduced reasons for thinking that these upper sands overlap both the middle and lower stages, and rest directly on the London Clay in the Aldershot district.[1]

### 2. Hampshire Basin.

The most complete sections of the Eocene series in the basin are found at each end of the Isle of Wight, in Alum and Whitecliff Bays, but the central and upper portions of the series, being more fossiliferous at certain places on the opposite coast of Hampshire, take their names from those places, *e.g.*, Bournemouth, Bracklesham, and Barton Beds.

In the Isle of Wight the beds are thrown up on end into a nearly vertical position (see fig. 112), and the thicknesses of the several divisions can thus be easily measured.[2] As in the London Basin, so also here the thickness of the Lower Eocenes increases from west to east, but that of the Middle Eocenes does not change much, being about 800 feet in Alum Bay, while in Whitecliff Bay it is about 750 feet.

#### Lower Eocene.

**Plastic Clay.**—This appears to represent the Reading Beds, neither the Thanet Beds nor the Oldhaven Beds being discernible in the Isle of Wight. It consists almost entirely of bright red and white mottled clays with several layers of brown sand, one of these being at the base and resting

[1] "Proc. Geol. Assoc.," vol. viii., and "Geol. Mag.," Dec. 3, vol. ii. p. 25.

[2] See Bristow's "Geology of the Isle of Wight, Mem. Geol. Survey;" Prestwich in "Quart. Journ. Geol. Soc.," vol. ii. p. 223; and Gardner, op. cit., vol. xxxv. p. 226.

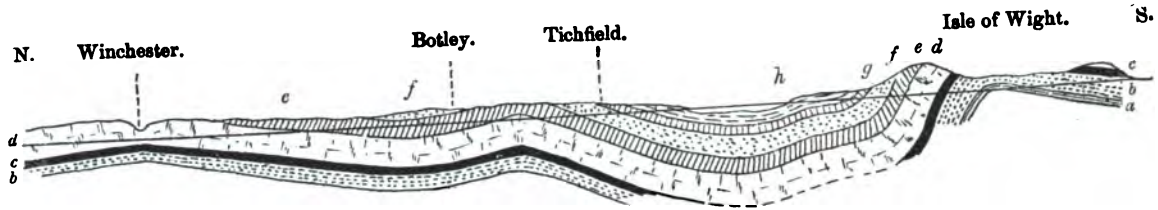



Fig. 112. Section through the Hampshire Basin and the Isle of Wight.
Distance about 35 miles.

*h*. Oligocene Beds.
*g*. Upper
*f*. Middle } Eocene.
*e*. Lower

*d*. Chalk.
*c*. Gault and Upper Greensand.
*b*. Lower Greensand.
*a*. Wealden.

on the chalk. No fossils except fragments of plants have yet been found in these plastic clays, and they do not therefore seem to be of marine origin. Their thickness in Whitecliff Bay is 163 feet, at Alum Bay 84 feet, and at Studland Bay (Dorset) they are hardly distinguishable..

**London Clay.**—With the exception of an outlier at Newhaven, the most easterly exposure of this division in this area is at Bognor, in Sussex, where beds of clay and calcareous sandstone, highly fossiliferous, are exposed on the shore, and are supposed to belong to the lower part of the London Clay.

At Whitecliff Bay, in the Isle of Wight, it is 307 feet thick, consisting for the most part of compact brown clay, somewhat sandy, and containing numerous septarian nodules of argillaceous ironstone; the upper part consists of sandy clays and sands in thin layers, with some lignite, and probably deposited in shallower water. At Alum Bay it is 200 feet thick, and still less in Dorset.

The basement pebble-bed at Whitecliff Bay is two inches thick, and is covered by buff sands (18 inches), and hard sandstone with *Ditrupa plana*. About 35 feet from the base there is a zone of *Panopœa intermedia* and *Pholadomya margaritacea*, and at about 80 feet a well-marked band of *Cardita Davidsoni*.

## Middle Eocene.

**Lower Bagshot Sands.**—These are yellow and white sands which are 248 feet thick at Alum Bay, and contain in their upper part layers of white pipe-clay which enclose leaves of plants in great abundance, the chief of them belonging to the genera *Dryandra*, *Aralia*, *Ficus*, *Quercus*, *Laurus*, *Cassia*, and *Cæsalpinia*.

These beds are also found in great force at Studland and Corfe, in Dorset, and they may be distinguished by the total absence of flint pebbles. Eastward they appear to thin rapidly, and are only 98 feet thick in Whitecliff Bay, while the overlying marine Bracklesham Beds become thicker in that direction. Mr. J. S. Gardner is inclined to unite them to the Lower Eocene, rather than to the Middle.

**Bracklesham Beds.**—These beds received their name from Bracklesham Bay in Sussex, where they contain marine shells throughout their whole extent along the shore, but there are no cliffs in which they can be measured.

The section in Whitecliff Bay exhibits the same marine type, and has been described in detail by the Rev. O. Fisher,[1] who divides the group into the four stages given below in descending order:—

| | | Feet. |
|---|---|---|
| A. | Chiefly green and blue clays (*Nummulites variolaria*) | 252 |
| B. | Yellow sands and sandy clays | 27 |
| C. | Sandy clays and green sands (*Num. lævigata*) | 123 |
| D. | Grey clays and green sands, with some lignite, but few fossils | 251 |
| | | 653 |

For the characteristic fossils see list on p. 440.

On reaching Alum Bay we find that the greater part of this group is represented by unfossiliferous sands and clays, probably estuarine beds, and that marine shells are only found in the uppermost 157 feet, which answer to Mr. Fisher's group A. The lower beds were formerly relegated to the Lower Bagshot, but their true position has been determined by Mr. Gardner, who has compared them bed by bed with those of the opposite cliffs of Hampshire.[2] The following are the divisions according to Mr. Gardner's reading, the letters and figures indicating their correlation with the Whitecliff and Bournemouth sections respectively.

| | | | Feet. |
|---|---|---|---|
| A. | 6. | Greenish sandy clays, with pebbles at base | 45 |
| | 5. | Yellow and white sands | 41 |
| | 4. | Bluish and brown clays, with lignite bands | 71 |
| B. | 3. | Bright coloured sands | 147 |
| C. | 2. | Dark sands and clays, with lignite | 98 |
| D. | 1. | Dark laminated clays and variegated sands | 153 |
| | | | 555 |

The succession of the Bournemouth and Boscombe beds has been carefully worked out by Mr. Gardner, who gives it as follows:—

[1] "Quart. Journ. Geol. Soc.," vol. xviii. p. 65.

[2] See "Proc. Geol. Assoc.," vol. vi. p. 88, and "Quart. Journ. Geol. Soc.," vol. xxxviii.

| | Feet. |
|---|---|
| 6. Dark sandy clays, with pebbles at base | 35 |
| 5. Highcliff sands, white | 31 |
| 4. Hengistbury clays | 57 |
| 3. Boscombe sands—yellow | ? 100 |
| 2. Bournemouth marine beds | 50 |
| 1. Bournemouth freshwater beds | ? 400 |

For the flora of the freshwater beds, see p. 438; the Boscombe Sands are regarded by Mr. Gardner as the equivalent of the Upper Bagshot Sands of the London Basin, but not by the Geological Surveyors, who look upon the latter as representing the sands above the Barton Clay.

## Upper Eocene.

**Barton Clay.**—The cliffs between Barton and Hordwell expose a good section of this clay, which is there 285 feet thick, and consists chiefly of bluish grey and brownish clays, containing many beautiful fossils in an excellent state of preservation; the genera *Voluta*, *Fusus*, *Conus*, *Murex*, *Phorus*, *Mitra*, and *Pleurotoma* are conspicuous, and are such as now inhabit warm seas (see list on p. 440).

In the Alum Bay section they are bluish, brown, and yellow sandy clays with a band of greenish sand in the middle; fossils are less abundant, though many occur; their thickness here is 250 feet.

At Whitecliff Bay clays occur on this horizon, but do not contain any fossils.

**Barton (or Hordwell) Sands.**—These include some 200 feet of yellowish sands, with which at Hordwell are intercalated clays containing marine shells of Barton species; at the summit there is a zone about 8 feet thick, characterized by *Cerithium pleurotomoides*, and this is classed by some with the overlying Headon Beds, and by others with the Hordwell Sands, because it also contains *Oliva Branderi*. It is in fact a transition zone, and might be grouped either with Eocene or Oligocene; similar passage beds are found in the Paris Basin (see *postea*).

At Alum Bay they consist of pure yellow and white sands without any fossils, and are estimated at from 140 to 200 feet in thickness.

At Whitecliff Bay their position is occupied by 200 feet of yellowish sands, in which a few casts of marine bivalves have been detected.

These beds are the Upper Bagshot Sands of the Geological Survey, so called because they are correlated with the upper part of the Bagshot series of the London Basin, but this correlation has recently been questioned (see p. 452).

### 3. Devonshire.

**Bovey Beds.**—These beds form a tract of low-lying heathland surrounded by hills and extending from Bovey Tracey to Kingskerswell, a distance of about nine miles. They consist of sands, clays, and lignites, and a boring at Bovey pierced the following beds:—

| | Feet. | in. |
|---|---|---|
| Superficial drift | 7 | 6 |
| Plastic clay | 2 | 6 |
| Quartz sand | 6 | 3 |
| Clays and lignites | 5 | 11 |
| Sand, clay, and a layer of conglomerate | 4 | 8 |
| Clays and lignites | 33 | 10 |
| Quartzose sand, with patches of clay | 11 | 1 |
| Clays and lignites | 53 | 4 |
| | 125 | 1 |

Their total thickness is supposed to be between 200 and 300 feet. At Kingsteignton there are 40 feet of light-coloured clays resting on sands, the clays yielding good pipe and pottery clay.

Mr. Woodward remarks that "the sedimentary matter was evidently derived from the waste of the (Blackdown) greensand, and of the granite rocks of Dartmoor."[1]

These beds are clearly of lacustrine origin, and they have yielded numerous plant remains, especially *Sequoia Coutssiæ*, and Mr. J. S. Gardner observes that the flora is so exactly like that of the Bournemouth Beds (Middle Eocene), "not only in species, but in their mode of preservation and grouping, that were specimens mixed they could not be re-separated."[2] Lithologically also, except for the presence

[1] "Geology of England and Wales," p. 279.
[2] "Proc. Geol. Assoc.," vol. vi. p. 88.

of lignite, they greatly resemble the Bournemouth Beds, so as to make it probable that both have derived their materials from the same sources.

### 4. IRELAND.

**Basaltic Series.**—This series has been mentioned in previous chapters as forming an elevated plateau in the north-east of Ulster; this plateau has steep escarpments on every side except toward Lough Neagh, and it is mainly composed of enormous lava-flows, but intercalated with the lowest of these are deposits of detrital and organic origin.

The basement bed of the series is generally a conglomerate containing flints derived from the Chalk, and resting on a very uneven surface of the underlying rocks (Chalk, Trias, &c., see fig. 105, p. 420). Above this there is a variable set of ochreous tuffs, iron ores, laterites, clays, and lignites, which are sometimes only a few feet thick, but sometimes swell out to thirty or forty feet, and are in some places intercalated with sheets of dolerite, which still further increase the thickness of these basal beds. Over them, however, are piled immense and extensive sheets of basalt and dolerite, which at Sleamish have a minimum thickness of 1,200 feet. The well-known columnar basalt at the Giant's Causeway is one of these sheets and overlies a bed of bole or laterite, while the basal conglomerate, here of considerable thickness, and not associated with clays or iron-ores, can be seen beneath massive dolerites near Dunluce Castle.

At Glenarm and near Antrim there are thick deposits of iron ore, the lower bed being a compact ferruginous earth known as lithomarge, which is sometimes 40 feet thick, and is overlain by pisolitic ore, and these occur some 600 feet from the base, and 400 feet from the top of the basaltic formation. At Glenarm they are associated with sandy clays and pebble beds, which enclose a seam containing well-preserved leaves and plant remains.

*Sequoia Coutssiæ*, *Macclintockia Lyellii*, and leaves of *Platanus* and *Rhamnus* have been identified by Baily, but further researches are being prosecuted by Mr. J. S. Gard-

ner, who considers the flora to be of Lower Eocene age, and not Miocene, as previously supposed.

**Lough Neagh Beds.**—Round the shores of this lake are deposits which may be of nearly the same age. According to Mr. Gardner[1] they resemble the Bovey Beds, "being a mass of alternating white, brown, greenish-blue, and red plastic clays, white and grey sand with irregular beds of lignite," and they have been pierced near Anaghmore to a depth of 260 feet without reaching the base. The relation of these beds to the neighbouring basalts has not yet been definitely ascertained, and the evidence for regarding them as Pliocene or Pleistocene appears to be insufficient.

### 5. Scotland.

**Volcanic Series.**—This is evidently a continuation of the Irish series, and attains still vaster proportions in Mull and the Inner Hebrides. Dr. A. Geikie writes, "the two great classes of recent lavas—the basaltic and the felspathic—are well represented among the Western Islands. The basaltic series is on the whole the older, since it is found to pass under massive sheets of pale grey and blue claystones, clinkstones, and porphyries belonging to the felspathic group."[2]

At Ardtun in the island of Mull there are several layers of tuff and clay, or shale, which are interstratified with sheets of basalt, and in these clays the Duke of Argyle discovered remains of leaves. The following is the section at Ardtun, according to the duke:[3]—

| | Feet. |
|---|---|
| 8. Basalt | 40 |
| 7. First "leaf bed" | 2 |
| 6. First tuff | 20 |
| 5. Second "leaf bed" | 2½ |
| 4. Second tuff | 7 |
| 3. Third "leaf bed" | 1½ |
| 2. Amorphous basalt | 48 |
| 1. Columnar basalt | 10 |
| | 131 |

[1] "Quart. Journ. Geol. Soc.," vol. xli. p. 87.
[2] "Proc. Roy. Soc. Edin.," 1866-7.
[3] "Quart. Journ. Geol. Soc.," vol. vii. p. 89.

"The leaf beds of Ardtun lie near the bottom of the whole volcanic series of the Hebrides, and above them comes a succession of sheets of basalt, &c., between 3,000 and 4,000 feet in thickness. Throughout this enormous mass of bedded igneous rock, layers of tuff often abounding in chalk-flints are instratified, and in one part of the cliffs of Innimore of Carsaig a bed of flints 25 feet thick lies between the dolerites. Thin lenticular seams or nests of coal likewise occur, but these only occupy small pond-like hollows of the original surface of the basalts, or dolerites, and are overlain directly with similar rock" (Geikie).

The Scùr of Eigg exhibits part of a valley, excavated out of the basalts, which has been filled up by thick flows of vitreous lava (Pitchstone), and at the bottom of the valley below the Pitchstone is a deposit of coarse shingle and sand with pieces of drifted pine-wood. The Pitchstone having resisted detrition better than the Basalts now forms a hill, while the ancient hills and valley-slopes have crumbled away.

### *Equivalents in Belgium and France.*

#### Belgium.

The Eocene area of Belgium may be regarded as the continuation of the London Basin, but it contains deposits which are older than any in England, and are the oldest Tertiary beds yet known in Western Europe. The following are the stages established by Dumont in Belgium.

**Montien.**—Friable and compact limestones, attaining a thickness of 300 feet, and lying in a trough which is excavated out of the chalk. Fossils are very numerous, and include both marine and freshwater species; the abundance of *Cerithium* and *Turritella* gives the fauna a Bracklesham aspect, but Professor Hébert remarks that it has also affinities with the highest Cretaceous fauna (Danien).

**Heersien.**—In two divisions: (1) marine sand with *Cyprina Morrisii*; (2) freshwater marls with plant remains and some marine shells. These beds are 100 feet thick, and are, probably, rather older than the Thanet Sands.

**Landenien.**—Gravels and sandstones, with marine fossils at the base (*Cyprina planata, Corbula regulbiensis*, &c.); sands, marls, and lignites above containing the fossils of our Woolwich Beds (*Melania inquinata*, &c.).

**Ypresien.**—Also in two divisions: (1) a brown clay, like our London Clay, but without fossils, 450 feet thick at Ostend; (2) Sands with *Nummulites planulatus, Turritella edita, T. hybrida, Lucina squamula*, and *Ditrupa plana*, a marine equivalent of our Lower Bagshot Sands.

**Paniselien.**—This, according to Cornet and Briart, rests on an eroded surface of the Ypresien superieur, and the fauna comprises a mixture of Ypresien and Bruxellien species, but both Hébert and Mourlon regard it as the terminal member of the Lower Eocene.

**Bruxellien.**—Sands and calcareous sandstones, answering to the greater part of the Bracklesham Beds; they contain *Fusus longævus, Voluta lineola, Natica labellata, Chama calcarata*, &c., with many fish and reptile remains.

**Laekenien.**—Similar sandy beds abounding in *Nummulites* (*lævigatus, scaber*, and *variolaria*), with *Ditrupa strangulata* and *Anomia sublævigata*.

**Wemmelien.**—Sandy beds with *Corbula pisum, Cardita sulcata, Fusus longævus*, &c., near Brussels, and a gravel at the base full of *Nummulites variolaria*.

### France.

The Eocene beds of the Paris basin include representatives of all these stages except the Montien and the Ypresien inferieur (London Clay). The following is a brief account of the French succession:—

**Basement Beds.**—Professor Hébert has recently described beds in the Paris basin which correspond to the older part of the Belgian series, though he thinks they are newer than the Montien. They consist of sands covered with a freshwater limestone (Calcaire de Rilly) and marls with marine fossils, some of which occur in the Montien.

**Sables de Bracheux** are sands containing *Cyprina Morrisii, Pholadomya cuneata*, and other fossils which are common in the Thanet Beds and Lower Landenien.

**Lignites du Soissonais** are plastic clays and sands with lignite bands, and correspond to the Reading Beds.

**Sables de Cuise.**—Nothing like the London Clay occurs in France, and the sands which overlie the Lignite beds contain the same fossils at the Ypresien sands of Belgium.

**Calcaire Grossier.**—This is the most fossiliferous formation in the Paris basin, and the middle portion yields the light yellow calcareous freestone which is the chief building stone of Paris. The group is divisible into three substages as follows:—

| | Feet. |
|---|---|
| 3. Upper, thin-bedded fissile limestones, with white and green marls and some beds of siliceous and dolomitic limestone: *Cardium obliquum, Cerithium denticulatum, C. lepidum, Lucina saxorum* . . . . . | 35 |
| 2. Soft thick-bedded limestones, some beds largely composed of *Miliola* and *Orbitolites: Cardium granulosum, Chama calcarata, Fusus bulbiformis, Turritella imbricataria* . . . | 40 |
| 1. Glauconitic limestones and sands, with a layer of pebbles at the base: *Cerithium giganteum, Cardium porulosum, Ostrea flabellula, Nummulites lævigatus* . . . . . | 25 |
| | 100 |

**Sables Moyennes.**—These are sands and sandstones, including the Gres de Beauchamp, lying between the Calcaire Grossier and the Calcaire de St. Ouen; they contain *Num. variolaria, Cyrena deperdita, Avicula Defrancei, Cerithium scalaroides*, and *C. Bouei*.

TABLE OF THE EOCENE STRATA OF BELGIUM, FRANCE, AND ENGLAND,

*Partly after Hébert and partly after Mourlon ("Géol. de la Belgique," p. 246).*

| | Belgium. | France. | England. |
|---|---|---|---|
| Upper Eocene. | Yellow sands.<br>Glauconitic clay.<br>Sands of Wemmel. | ? Sables de Mortefontaine.<br>Gres de Beauchamp.<br>Sables de Guèpel. | Barton Sands.<br>Barton Clay. |
| Middle Eocene. | Wanting.<br>Laekenien.<br>Bruxellien. | Calc. grossier superieur.<br>Calc. grossier moyen.<br>Calc. grossier inferieur. | Bracklesham Beds. |
| Lower Eocene. | Paniselien.<br>Ypresien { sands. / clay.<br>Landenien { upper. / lower.<br>Heersien { upper. / lower.<br>Montien. | Sables de Cuise.<br>Wanting.<br>Lignites du Soissonais.<br>Sables de Bracheux.<br>Calcaire de Rilly.<br>Sables de Rilly.<br>Absent. | Lower Bagshot.<br>London Clay.<br>Woolwich Beds.<br>Thanet Sands.<br>Absent.<br>Absent. |

## B. Oligocene Series.

The name *Oligocene* was proposed for this series by Professor Beyrich in 1854, who showed that they contained an important fauna which is on the whole distinct from that of the typical Eocene strata of England, France, and Belgium, and that they attained a considerable development in Northern Germany. The older classification arranged these beds partly in the Eocene and partly in the Miocene system, but this rendered it necessary to draw a line of separation between the two so-called systems in every area of deposition, and in the midst of a perfectly continuous series. The difficulty of making this separation, and the close connection of the faunas of the groups which were formerly called "Upper Eocene" and "Lower Miocene" respectively, has induced geologists to accept Professor Beyrich's suggestion to unite these groups under the name of Oligocene. Their fauna, however, is not so distinct from that of the Eocene (as now restricted) as to entitle the series to be regarded as a distinct system, but forms the upper portion of the Lower Tertiary or Hantonian system.

The following are the English groups belonging to the Oligocene series:—

| | | | Feet. |
|---|---|---|---|
| Upper. | Wanting in England. | | |
| Middle. | Hempstead Beds | | 105 |
| | Bembridge Beds | Bembridge marls | 140 |
| | | Bembridge limestone | 20 |
| | | Lower or Osborne marls | 90 |
| Lower. | Headon Beds | Upper, freshwater | 40—80 |
| | | Middle, marine | 100—30 |
| | | Lower, brackish | 40—70 |
| | | | 535 |

### *Life of the Period.*

Very few genera of invertebrate animals date from Oligocene times, the species found in these deposits being simply the modified descendants of those which prevailed in Eocene times; a great number of mammalian genera

are, however, confined to the Oligocene division, and of these the following are the most important:—*Adapis*, *Anchitherium*, *Anoplotherium*, *Anthracotherium*, *Cainotherium* (*Microtherium*), *Chœropotamus*, *Dorcatherium* (*Amphitragalus*), *Hyopotamus*, *Hyœnodon*, *Microchœrus*, and *Xiphodon*. Besides these some Eocene forms continued to exist, such as *Palœotherium*, *Dichodon*, *Dichobune*, and *Hyracotherium*.

*Adapis* is a remarkable creature which is said to have relations with the hoofed quadrupeds, insectivores, and the lemurs, and may therefore be the ancestor of the monkey tribe.

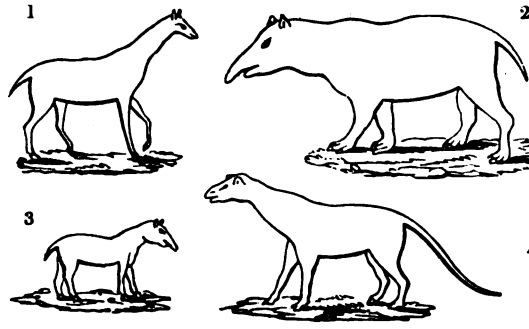



Fig. 113. Mammals of the Oligocene Beds.

1. Xiphodon gracile.
2. Palæotherium magnum.
3. Palæotherium minus.
4. Anoplotherium commune.

*Anchitherium* is regarded as the ancestor of the horse, but had three hoofs on each foot, and was no larger than a sheep or Shetland pony.

*Anoplotherium* and *Anthracotherium* were Ungulates of comprehensive types, *i.e.*, combining the structural characters of many different modern genera, such as hippopotamus, rhinoceros, pig, and horse. Of the first, five species are known, the largest being about the size of an ass, but having a very long and thick tail, which may have assisted him in swimming like that of the otter (see fig. 114). Of *Anthracotherium* seven species are known, varying in size from the size of a hog to that of a hippopotamus.

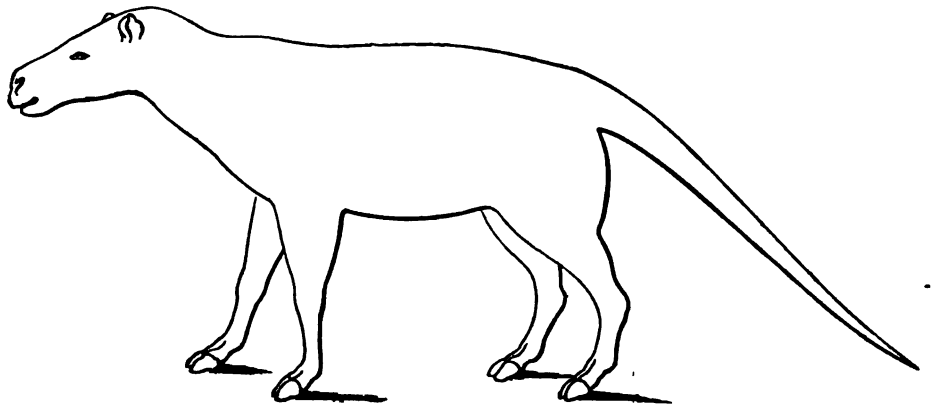


Fig. 114. Anoplotherium commune.

Restored outline of the animal, after Cuvier, about $\frac{1}{72}$ of natural size.

*Caimotherium* and *Dorcatherium* were small hornless forms of deer allied to the Chevrotains.

*Hyopotamus* was a water-hog; *Chœropotamus* and *Microchœrus* being also hog-like creatures. *Hyœnodon* was a carnivore, with teeth like the Marsupial *Thylacinus* or Tasmanian wolf, and it doubtless preyed on the vegetable feeding Ungulates. *Xiphodon* was an ancestral form of deer, and like *Dichobune* was without any horns.

## Fossils of the Headon Group

(Marine beds).

*Actinozoa.*—Madrepora Solanderi, Balanophyllia granulata, Solenastræa gemmans, S. Kæneni.

*Lamellibranchs.*—Ostrea flabellula, O. ventilabrum, Cytherea incrassata, Cardita deltoidea, Corbula cuspidata, Psammobia compressa, Ps. solida (rudis).

*Gasteropoda.*—Pisania (Buccinum) labiata, Murex sexdentatus, Pleurotoma Headonensis, Ancillaria subulata, Cancellaria muricata, Voluta spinosa, V. decora, Neritina concava.

(Brackish and freshwater beds.)

*Plants.*—Typha sp., Chara Lyellii.

*Lamellibranchs.*—Cyrena obovata, C. cycladiformis, Unio Solandri, Potomomya plana, P. gregaria.

*Gasteropoda.*—Potamides (Cerithium) concavus, P. ventricosus, P. cinctus, Melanopsis brevis, M. fusiformis, Limnæa longiscata, L. fusiformis, Planorbis euomphalus, P. lens.

*Reptiles.*—Crocodilus Hastingsiæ, Alligator Hantonensis, Gavialis Dixoni, Emys crassus, Trionyx marginatus, and five other species.

*Mammals.*—Palæotherium parvum, P. annectens, Dichodon cuspidatus, Dichobune cervinum, Anoplotherium commune, Microchœrus erinaceus.

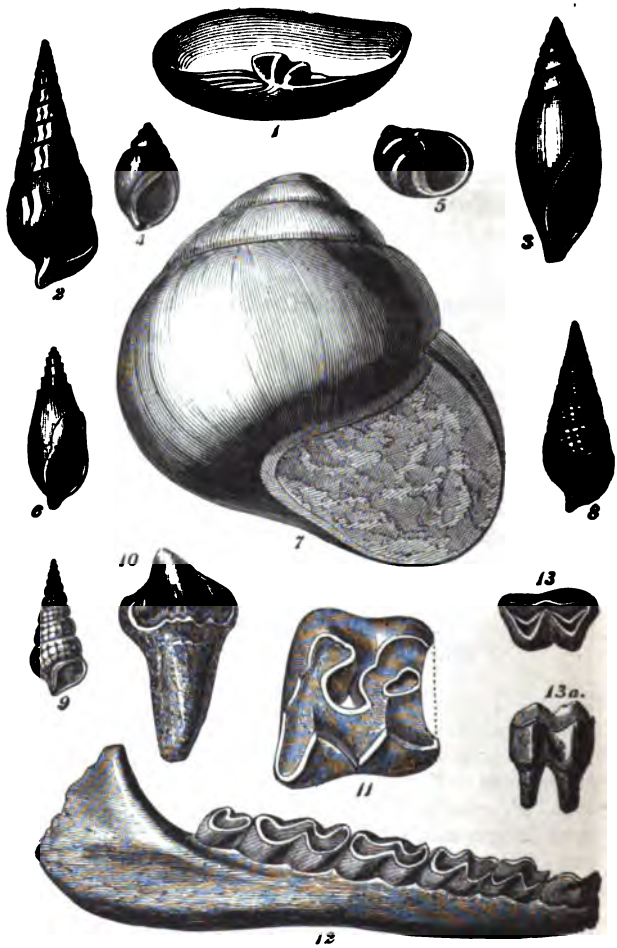



Fig. 115. Oligocene Fossils.

1. Potomomya gregaria.
2. Potamides concavus.
3. Melanopsis fusiformis.
4. Melanopsis brevis.
5. Neritina concava.
6. Melanopsis carinata.
7. Helix globosa.
8. Potamides plicatus.
9. Potamides ventricosus.
10. Anoplotherium commune (canine).
11. Palæotherium medium (molar).
12. Palæotherium minus (lower jaw).
13. Dichobune cervinum (tooth).

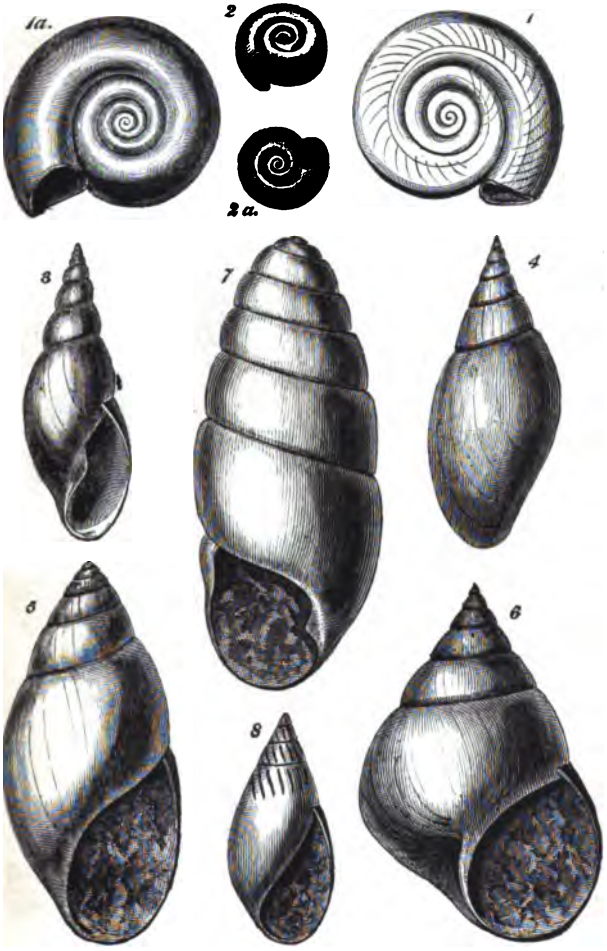



Fig. 116. Oligocene Fossils.

1. Planorbis euomphalus.
2. Planorbis obtusus.
3. Limnæa longiscata.
4. Limnæa fusiformis.
5. Achatina costellata.
6. Paludina orbicularis.
7. Bulimus ellipticus.
8. Achatina sp. nov.

## Fossils of the Bembridge Group.

*Plants.*—Flabellaria lamanonis, Chara Lyellii, Ch. medicaginula.

*Lamellibranchs.*—Cyrena pulchra, C. semistriata, Ostrea vectensis.

*Gasteropoda.*—Melania muricata, M. excavata, M. turri-

Fig. 117. Flabellaria Lamanonis (¼).
From the Bembridge Beds.

tissima, Melanopsis carinata, Cerithium mutabile, Limnæa longiscata, Paludina lenta, P. orbicularis, Planorbis discus, P. obtusus, P. rotundatus, Bulimus ellipticus, Achatina costellata, Helix globosus, H. d'Urbani, Cyclotus cinctus.

*Reptiles.*—Trionyx incrassatus.

*Mammals.* — Anoplotherium commune, Palæotherium crassum, P. magnum, Chœropotamus Cuvieri, Dichobune cervinum.

## Fossils of the Hempstead Group.

*Plants.*—Chara helicteres, Ch. tuberculata.

*Crustacea.*—Candona Forbesii, Cytheridea Mulleri.

*Lamellibranchs.*—Ostrea callifera, Corbula subpisum, C. vectensis, Panopæa Heberti (minor), Unio Austeni, Lucina Thierensi.

*Gasteropoda.*—Cerithium elegans, C. plicatum, Natica labellata, Rissoa Chastelii, Voluta Rathieri (Forbesii), Nematura parvula.

*Reptiles.*—Trionyx incrassatus.

*Mammals.*—Hyopotamus bovinus, H. vectianus.

### *Stratigraphy.*

#### Britain.

**The Headon Series** was subdivided by Professor Forbes into lower, middle, and upper stages, the first and third being brackish and freshwater beds, and the second containing marine fossils:—

The Lower Headon Beds are 67 feet thick at Headon Hill, in Alum Bay, but only 40 in Whitecliff Bay at the east end of the Isle of Wight. They consist chiefly of greenish clays with beds of sand and thin bands of freshwater limestone; *Limnæa longiscata, L. caudata, Planorbis euomphalus. Pl. lens, Paludina lenta, Cyrena cycladiformis,* and *Unio Solandri* are common fossils.

At Hordwell Cliff, on the coast of Hampshire, the thickness of the Lower Headon is variously estimated at 66 and 83 feet; certain of the beds have yielded many mammalian and reptilian remains.[1]

The Middle Headon are only 30 feet thick at Headon,

[1] See Tawney and Keeping, "Quart. Journ. Geol. Soc.," vol. xxxix. p. 566.

and 23 feet at Colwell Bay, but at these localities they consist chiefly of clays, while at Whitecliff Bay thick beds of sand are interstratified, and the thickness amounts to 100 feet. At Headon the fossils are principally of brackish-water species, *Cerithium concavum*, *C. ventricosum*, *C. pseudocinctum*, and *Neritina concava* being abundant, though the central part contains marine fossils. In Colwell Bay, to the north, this part assumes a distinctly marine character, and is known as the "Venus bed," from the presence of *Cytherea incrassata;* oyster banks composed of *Ostrea flabellula* also occur, together with *Nucula similis*, *Cyrena obovata*, *Murex sexdentatus*, *Voluta spinosa*, &c.

At Whitecliff Bay the marine character is still more strongly marked, and the lower clay beds contain a peculiar fauna, with some species that are only elsewhere found at Brockenhurst in Hampshire (New Forest).

The Brockenhurst Beds are entirely marine, and contain a large number of marine univalves, bivalves, and corals, of which the following are some: *Voluta spinosa*, *Conus dormitor*, *Cancellaria elongata*, *Pleurotoma transversaria*, *Cardita deltoidea*, *Cytherea incrassata*, *Corbula cuspidata*, and six species of *Solenastrea*. There has been much discussion about the exact horizon which these beds occupy in the Headon series.[1] All are agreed that they correspond with the Middle Headon of Whitecliff and Colwell Bays, and if this is the same as the marine band of Headon Hill, their position is clear; but Professor Judd expresses his opinion that the "Venus bed" of Colwell Bay overlies the Upper Headon, and that the Brockenhurst Beds are therefore a separate group lying between the Headon and the Bembridge groups. This view, however, has not been supported by subsequent writers, most of whom endorse that of Professor Forbes and the Geological Survey.

The Upper Headon Beds are about 80 feet thick at the western end of the island; at Headon Hill they include several thick beds of limestone, which form conspicuous objects in the cliff, and are crowded with fossils of freshwater genera, *Limnæa*, *Planorbis*, *Paludina*, and *Bithynia;* these limestones, however, are quite local, thinning out

[1] Judd, "Quart. Journ. Geol. Soc.," vol. xxxvi. p. 137; Tawney and Keeping, op. cit., vol. xxxvii. p. 85.

rapidly to the north and east, and only one such bed is found at Colwell Bay. At Whitecliff the beds measure only 41 feet, and consist entirely of greenish clays and sands; similar beds are found at Norris and East Cowes, on the north coast of the island. The principal fossils of this stage are *Melania muricata*, *Cerithium lepidum*, *Cer. margaritaceum*, *Cyrena obovata*, and *Potomomya plana*.

**Bembridge Group.**—The lower beds of this group were originally included by Webster, 1816, with the Upper Headon Beds, but were separated by Professor Forbes in 1853, under the name of the St. Helen's Beds, afterwards changed to "Osborne Beds." Under the latter name they are described in the "Memoirs of the Geological Survey," and have received a separate colour on the map, but as the fossils they contain are not distinctive, and as they are never more than 70 feet thick, they are certainly not entitled to rank as a primary division. Mr. Keeping agrees with Webster in considering that they are more closely connected with the underlying Headon Beds, but Professor Judd groups them with the overlying Bembridge group, under the name of Lower Bembridge marls.[1] Until this point is settled by competent observers, I adopt Professor Judd's classification, though not his thicknesses. The Bembridge group then consists of three members, as below:—

| | Headon. | Whitecliff. |
|---|---|---|
| 3. Upper marls . . | not seen . | 130? |
| 2. Bembridge limestone | 15 . | 25 |
| 1. Lower marls . . | 60 . | 90 |

The lower or Osborne marls at Headon Hill and Colwell Bay consist of blue and red marls with calcareous concretions, but few fossils. At Whitecliff Bay they consist of dark green clays and sands, but are much concealed by landslips, and the best sections occur along the north-eastern coast from Osborne to Nettlestone Point; here, however, they assume a very different facies, the lower 20 feet consisting of marls, with bands of hard yellowish sandy ragstone and shell limestone full of *Paludina lenta* and

[1] "Quart. Journ. Geol. Soc.," vol. xxxvi. p. 169.

*Melania excavata* (Nettlestone Beds); the upper 50 feet consisting of green and yellow sands alternating with marls and clays of white, green, and yellow tints (St. Helen's Sands), well seen at Priory Point, where they contain *Melania excavata*, *Planorbis obtusus*, *Limnæa longiscata*, and *Cyrenæ*.

The Bembridge limestone is a cream-coloured stone with interstratified marls; sometimes it is compact, sometimes quite tufaceous and concretionary; it is quarried at Headon Hill, at Sconce near Cliff End, and at Binstead near Ryde, and it is also exposed at Bembridge Point and in Whitecliff Bay. Its contents are terrestrial and freshwater, many species of *Helix*, *Bulimus*, *Achatina*, *Cyclotus*, *Clausilia*, *Limnæa*, *Planorbis*, and *Paludina* occurring, with oviform bodies which are supposed to be the eggs of the large *Bulimi*; stems and seeds of *Chara* are common, and mammalian remains are found in the Binstead quarries.

The upper or Bembridge marls, as described by Professor Forbes, were limited to the 60 feet of deposits which overlie the Bembridge limestone, but as this classification necessitates drawing a line in the midst of freshwater strata without any corresponding change in the fauna, Professor Judd proposes to extend their range up to the horizon where the marine Hempstead species begin to appear. The typical section at Hempstead is as follows:—

| | Feet. |
|---|---|
| 3. Bluish grey shales and marls . . . . . | 70 |
| 2. Band of black carbonaceous clay . . . . . | 2 |
| 1. Blue and green marls and clays . . . . . | 62 |

The lower beds contain *Paludina lenta*, *Melania muricata*, and *M. turritissima* in abundance, with *Melanopsis carinata*, *Cyrena pulchra*, and *C. semistriata*; most of these occur also above the black band associated with *Hydrobia Chastelii*.

At Whitecliff Bay there are variegated red and green marls, with layers of sand and a bed of sandy freshwater limestone containing *Bulimus* and *Achatina*, about 50 feet above the Bembridge limestone; above this are similar marly beds for 40 feet, but no sign of the Hempstead "black band."

**The Hempstead Beds** as now limited are only 105

feet thick, but may originally have been very much thicker, as they are only exposed at one locality, Hempstead or Hamsted, near Yarmouth, and their top is not seen. Their base is marked by a shelly layer from 1 to 4 feet thick, which is conspicuous in the cliff, and is known as the "white band." This layer is a compacted mass of shells, broken and perfect, and a great part of it consists of single valves of *Cyrena semistriata;* with this are *Cerithium Sedgwickii, C. inornatum, Melania fasciata, Hydrobia Chastelii,* and *Panopœa minor;* bones of fish and teeth of *Hyopotamus bovinus* also occur.

The white band is overlain by 40 feet of yellow and green marls without fossils, succeeded by shales and clays with *Unios* and *Paludina lenta.* Above these are beds of more estuarine origin, containing *Cerithium plicatum, Cer. elegans,* and *Corbula vectensis,* associated with *Hydrobia, Melania,* and *Cyrena.*

The highest beds, of which only 10 or 15 feet are seen, consist of brown and greenish clay, and contain a purely marine fauna (see list on p. 467); they are often called the "Corbula Beds" from the abundance of *Corbula pisum* and *C. vectensis.*

The only other place where Hempstead Beds occur is at Parkhurst Forest, north-east of Newport, but this outlier has not yet been explored.

### France.

The following is a tabular view of the Oligocene succession in the Paris basin.

| | |
|---|---|
| Upper. | Calcaire de la Beauce, a freshwater limestone, replaced towards the north by the millstones of Montmorency—hard siliceous cellular limestones. |
| | Grès de Fontainebleau, hard sandstones. |
| Middle. | Sables de Fontenay, yellow sands. |
| | Marls, with oyster-beds (*O. longirostris* and *O. cyathula*), with the Calcaire de Brie at the base. |
| | Green marls, with *Cerithium plicatum.* |
| Lower. | Blue and white marls (few fossils). |
| | Lacustrine gypsum, containing mammalian remains. |
| | Marine gypsum and marls. |
| | Green sands of Monceaux (*Cerithium Cordieri*). |
| | Calcaire de St. Ouen, a freshwater limestone. |

Authorities differ as to the base line of the system, and the beds below the lacustrine gypsum are referred by some to the Eocene; they contain *Cerithium tricarinatum, C. pleurotomoides, Turritella incerta, Pholadomya ludensis, Crassatella Desmaresti*, &c., and may perhaps be regarded as passage beds between Eocene and Oligocene. A similar passage occurs at Hordwell in Hampshire, and some of the same fossils occur there. The gypsum of Montmartre has yielded no less than fifty species of mammalia (*Anoplotherium, Palæotherium, Hyænodon*, &c.). Whether the Fontainebleau sandstone should be classed as Upper or Middle Oligocene is a moot point, but M. Dollfuss classes it as above.

The Plateau de la Beauce is a broad table-land, lying between the basins of the Seine and the Loire, and is formed by the freshwater limestones and marls of the Calcaire de la Beauce; these beds attain a thickness of 80 feet, and were evidently deposited in a wide, though probably shallow lake.

Still more extensive lakes existed in central France throughout the Oligocene period, and have left their monuments in the lacustrine strata of Auvergne, Cantal, and Velay. The northernmost of these lakes occupied the valley-plain of the Allier, formerly known as the Limagne d'Auvergne; the average breadth of this tract is twenty miles, and its length from near Nevers to Brioude nearly 100 miles; it consists of nearly horizontal strata of sandstone, marl, and limestone, which often rise into low hills capped by fragments of ancient lava-streams (see "Physical Geology," p. 393, and Plate II.); this tract is bounded on either side by lofty hills of granite and gneiss, which rise to a height of 1,600 feet above the plain, and 3,000 feet above the sea, while the western ridge supports a chain of volcanoes, whence lava-streams flowed from time to time into the valleys below. The deposits of the plain exhibit the following succession:—

| | Feet. |
|---|---|
| Laminated marls, with gypsum . . | about 50 |
| Limestones and marls . . . . | „ 200 |
| Laminated green and white marls . . | „ 700 |
| Red marls, sandstones, and cornstones . . | variable. |
| Conglomerates and sandstones. . . . | variable. |

But these beds cannot all be seen in one locality; the arenaceous strata are probably thickest near the margins of the ancient lake, while the marls and limestones constitute a central deposit which is about 1,000 feet thick. The lowest beds contain few fossils, but bones of *Palæotherium* have been found; the marls have yielded a large assemblage of fossils—Ungulates, Carnivora, Rodents, Opossums, Birds, Crocodiles, Tortoises, and Snakes, with numerous land and freshwater molluscs; small Ostracod Crustacea (*Cyprides*) also abound in the marls.

Some of the limestones are oolitic, others are entirely made up of the cases of caddis-worms cemented together by calcareous matter, and in the Cantal there is a chalky limestone containing siliceous nodules like our flints.

Judging from the succession of mammalia in this lacustrine series, deposition appears to have commenced in Lower Oligocene times, and to have continued uninterruptedly through the Miocene and Pliocene epochs, for the higher beds contain *Mastodon, Dinotherium, Tapirus*, &c.

## Belgium.

Oligocene beds are found near Antwerp, and again near Maestricht and Tongres in Belgium, and exhibit a more continuous series of marine deposits than in England or France, though they do not appear to extend over the whole period of Oligocene time. Belgian geologists recognize two groups, termed respectively *Tongrian* and *Rupelian*.

The *Tongrian*, as limited by Mourlon,[1] consists of sands (20 to 60 feet) with an abundant marine fauna, many species occurring also in our Brockenhurst Beds, such as *Ostrea ventilabrum, Voluta decora, Cytherea Solandri*, so that they doubtless correspond to the middle and upper part of our Headon group.

The *Rupelian* has at the base green marls (Henis clay), containing fossils of freshwater and terrestrial genera, *Melania, Planorbis, Limnæa, Cyclostoma, Succinea*, and *Pupa;*

[1] "Géologie de la Belgique," p. 249.

above these are marls and sands with estuarine fossils (the *Cerithium* sands of Klein Spawen and Bergh), containing *Cer. elegans, Cer. plicatum, Cyrena semistriata, Pectunculus obovatus*, and *Pecten Hœninghausi*, &c. These fluviomarine beds have a thickness of about 30 feet. They are succeeded by a stiff sandy clay with septarian nodules, and somewhat resembling the London Clay in general aspect; its fossils, however, are different, the commonest being *Nucula compta* (*Leda Lyelliana*); others are *Corbula subpisum, Cancellaria evulsa, Cassidaria depressa*, and *Aturia ziczac*, the last being a deep sea form surviving from the Lower Eocene; teeth of sharks (*Lamna contortidens, Carcharodon angustidens*, &c.) also occur. This clay attains a thickness of 120 feet, and even more in some places; near Looz the upper part is replaced by white sands.

The Rupelian appears to be the equivalent of our Bembridge and Hempstead Beds, and nothing corresponding to the Upper Oligocene of France is found in Belgium (see table on opposite page).

### SWITZERLAND.

An immense lacustrine area, sometimes invaded by the sea, existed in Switzerland during Oligocene and Miocene times, the strata accumulated within its limits attaining a thickness of 7,000 or 8,000 feet.

"Nothing," says Jukes, "is more calculated to strike the geological traveller on his first visit to Switzerland than the vast deposit of the 'Molasse,' occupying the central region between the Alps and the Jura. This is the country of the great lakes, extending from that of Geneva to that of Constance. The hills by which these lakes are environed have all the rugged and broken character of mountains, and rise in peaks of various altitudes up to that of 6,050 feet, which is the height of Rhigi Kulm. These hills which, if they were not overshadowed by the still loftier Alps, would themselves be celebrated mountains, are composed from top to bottom of beds of sand and gravel, occasionally compacted into sandstones and conglomerate, of more recent origin than the newest beds of the Isle of Wight."[1]

[1] Jukes' "Manual of Geology," second edition, p. 662.

## Table of the Oligocene Strata of Western Europe,

*After Professor Judd, with slight modification.*

| | Hampshire. | Paris Basin. | Belgium. | Germany. | Switzerland. |
|---|---|---|---|---|---|
| Upper Oligocene. | Absent. | Calcaire de la Beauce.<br>Grès de Fontainebleau. | Absent ? | Rhenish brown coal deposits.<br>Cyrena marls. | Brown coal beds (Aquitanien). |
| Middle. Oligocene. | Hempstead Beds.<br>Bembridge Beds. | Sables de Fontenay.<br>Marls and Calcaire de Brie.<br>Green marls. | Argile de Boom.<br>Sands of Bergh, &c.<br>Green clay of Henis. | Septarian clay.<br>Marine sands of Mayence.<br>—— | Lower marine Molasse. |
| Lower Oligocene. | Upper Headon.<br>Middle Headon.<br>Lower Headon. | Marls and lacustrine gypsum.<br>Marine marls and gypsum.<br>*Cerithium* zone.<br>St. Ouen limestone. | Tongrian Sands.<br>Absent. | Marine deposits of Egeln.<br>? Lower brown coals. | Upper Flysch ? |

The lowest beds are marine, and contain the same fossils as the lower Rupelian beds of Belgium, but have no great thickness; these are overlain by the "red molasse," which consists of red conglomerates, sandstones, and marls, and attains a thickness of 6,000 feet; from these beds a large number of plant remains have been collected, including species of *Sequoia*, alders, birches, figs, laurels, cinnamon-trees, and evergreen oaks.

### *Physical Geography.*

The gradual upheaval of the British area, which took place at the close of the Cretaceous epoch, continued until the greater part of our islands were raised above the level of the sea, and once more became part of a continent which stretched far westward and southward of their present limits. In imagining the aspect of this land we must remember that a large part of it was the upraised bottom of the Cretaceous ocean, and though, doubtless, portions of the Chalk were removed by erosion during upheaval, especially those which bordered the rising coast-lines of Wales and other hilly districts, yet we must suppose that the great sheets of chalk which occupied the intervening tracts would escape total destruction, and would form plains uniting Wales to the Pennine range and Ireland to England and Scotland. The Jurassic rocks must have been entirely concealed, and the strata exposed to subaerial waste would be the Chalk and the Palæozoic rocks of what we may call the western and northern highlands.

The upheaval does not seem to have been quite a uniform movement, but to have been more rapid in the west and north than in the south-east, and it is doubtful whether the extreme south-eastern part of England was ever raised into dry land before the deposition of the Lower Eocenes; and if it were, the time that it remained above water was probably very short. Moreover, the east and west anticlinal axes of the Weald seem to have been initiated during the formation of these Eocenes, for the Woolwich Beds overlap the Thanet Sands southward as well as westward, and the Oldhaven Pebble-beds overlap all the underlying

deposits so as to rest directly upon the Chalk near the edge of the North Downs; hence, as Mr. Whitaker remarks,[1] "one is warranted in concluding that the planing down of the Chalk that once spread over the Wealden tract began in Lower Eocene times, and that the pebble beds of Bromley, Blackheath, &c., are one of the direct results of that denudation." There are also traces of another east and west axis along the 52nd parallel of latitude in the eastern trend of the Jurassic escarpment, and in the remarkable fault along the Chalk escarpment near Royston.

It would, therefore, appear that the Lower London Tertiaries were deposited in a gulf or estuary which opened eastward into a Belgian sea and narrowed westward toward Wales, and that it received the waters of a river flowing from the west,—a river that may have occupied the valley of the Bristol Channel and was, doubtless, swollen by powerful affluents from the Welsh mountains. In the estuarine Woolwich Beds, with their lignites and fossiliferous clays, we have part of the delta of this river, while the marine sands of Kent seem to have been arranged by the currents of the sea into which it flowed.

Professor Prestwich and Mr. J. S. Gardner agree in thinking that there was a considerable extent of open sea to the east and north-east of England, and that much of the Channel area and of central France was land during early Eocene times, the land being continuous across the space between Brittany and Cornwall, so that the northern sea was entirely cut off from communication with the warmer seas of more southern regions. Professor Prestwich has also suggested[2] that the fauna of the Lower Eocene had a yet older existence in a more northern province, the generic forms of a north temperate region spreading southward along the shores of this sea, and giving a more recent aspect to the Lower Eocene fauna as compared with that of the Middle Eocene, when geographical changes led to the introduction of a fauna from the more southern seas.

Another gulf of this northern sea seems to have ex-

[1] "Geology of the London Basin, Mem. Geol. Survey," vol. iv. p. 241.

[2] "Quart. Journ. Geol. Soc.," Address for 1871, p. 56.

tended into the north of France and to have touched our southern shores, unless the Plastic Clay of the Isle of Wight is a lacustrine formation. Northern France at this time probably exhibited a network of shallow seas and lagoons with intervening tracts of land.

It is clear that during the deposition of the London Clay considerable depression took place, and that the gulf above indicated was greatly broadened, especially in a south-westerly direction, through Hampshire and Dorset, toward the opening of the English Channel; it did not, however, extend to the Paris area, where no marine beds of this age occur. This sea received the detritus of the western land which the great river above-mentioned continued to pour into it; the fossils of the London Clay in the Hampshire Basin, *Pinna*, *Panopæa*, *Turritella*, &c., indicate a shallow sea with an average depth of 10 to 20 feet, and seldom attaining one of 30 or 40 feet, but in the eastern part of the London Basin its depth has been estimated at 100 fathoms (600 feet). "Throughout the deposition of the London Clay the subsidence of the sea-bed must have been quiet and gradual. The marine fauna, although still seen by comparison with those of succeeding beds to be relatively temperate-looking, and to belong to the Northern sea, has a far more torrid aspect. This is owing to a warmer period having set in, produced probably by the rise of land between England and North America, which, there is evidence to show, took place about this time, and completely shut off the cold Arctic currents. The temperature of the sea thus increased, doubtless acted upon the land, and enabled a tropical and most luxuriant and varied fauna and flora to migrate thither and become established. Myriads of fruits and seeds, and the bones of many species of turtle and crocodile, whose habits would cause them to be buried in such a position, as well as of snakes, birds, &c., are found at Sheppey just as they were stranded and buried in the delta-mud of the great Western river."[1]

In the succeeding deposits of the Lower Bagshot group we have proof of the silting up of this gulf, the more western

[1] Gardner in "Proc. Geol. Assoc.," vol. vi. p. 93.

beds of Corfe, Studland, and Alum Bay having been accumulated, according to Mr. Gardner, in a wide valley or shallow lake, and he remarks that "the complexity of the stratification suggests that two rivers united in this valley, and shows plainly that the waters must, in any case, have been rapid at times, and subject to periodical fluctuations of volume." He gathers also, "from the absence of lignites in some parts of the series, that there were, in the upper parts of the river, lakes such as those of Bovey Tracey, which intercepted drifting timber; its abundance in other beds marking the time when these had been filled in" (loc. cit., p. 95). The total absence of flints seems to show that no chalk was then exposed to the westward of this area, and the materials of the pipe-clays are clearly derived from the detrition of granitic rocks such as occur in Devon and Cornwall.

"In the Bournemouth Beds we have deposits of the same river, but in a more open and level valley, and in closer proximity to the sea. In all the lower or freshwater series we have no sign of the presence of sea water, and when we do find it in the higher beds to the east, it is not that the river deposits encroached there on the sea, but that the land gradually sank, and allowed the sea to cover them."

"It is of great interest to trace through these beds the change from a comparatively upland flora to a valley, and then to a swamp flora; to follow out the lowering of the land until it became sea; to trace the sea, first trickling in, as it were, and forming lagoons, then overwhelming the mud deposits formed by these lagoons, with shingle and sand; to realize, in fact, the actual shore-line, now marked by river deposits, full of plant remains on one side, and a sea fauna with sharks' teeth on the other."[1]

The contemporary lacustrine deposits in Devonshire (p. 453) suggest that the Teign was a tributary of one of the rivers which entered the sea near Bournemouth. Dartmoor and the Haldon Hills existed then as now, and the outlet of the Bovey lake appears to have been in the direction of Torquay, and not through the modern estuary of the Teign. From Torbay it doubtless ran east-

[1] Gardner, loc. cit. p. 95.

ward and joined the waters of the Exe, the united streams continuing to pursue an eastward course, and ultimately pouring the felspathic and arenaceous detritus derived from the Devonshire hills into the estuary which ran through Dorset and Hants.

"The series of marine beds from Bournemouth to Highcliff, which belong to the Bracklesham Beds, are the shore deposits of the Southern sea. The Bracklesham series proper show a gradually deepening sea; for, while the beds of sand which are prevalent in the lower stages show shallow water, the clay beds above them were formed in a deeper sea, and contain deeper water mollusca. In comparing the marine fauna with that of the London Clay, its very much more tropical character is apparent. Many southern types of mollusca abound in it which are scarcely represented in the London Clay. Their aspect is completely different, and though separated geologically by but a short interval of time, hardly any species are common to both, while the lithological characters of the formation are widely and persistently dissimilar. If we examine, on the other hand, the terrestrial fauna and flora of these and the intervening strata, we see that no increase of temperature or change had taken place in the climate, and that the land was still inhabited by similar groups of reptiles and plants. It is, therefore, plain that the sea alone had changed, and become much warmer, for depressions had enabled the Southern sea, then occupying part of France, to advance and to overlap to a small extent the older deposits."[1]

Coming to the period of the Barton Clay, Mr. Gardner continues, "the depression which lasted throughout the Bracklesham period was prolonged into that of the Barton Beds, which are found to indicate still deeper seas. A remarkable change in the fauna almost suddenly took place. We see an influx of mollusca of a comparatively temperate aspect, recalling strongly those of the London Clay, many of the species which have disappeared in the intermediate Brackleshams, reappearing in the Barton series.

"At the same time there was a migration of the more tropical of the Bracklesham forms, including all the larger

[1] Gardner, loc. cit., p. 96.

cones, cowries, bullæ, cerithia, the great cardia and nummulites, only twenty-five of the least tropical-looking mollusca remaining to mix with the new fauna. This can only be explained by the mingling of the waters of the Northern and Southern seas, due to the temporary submergence or destruction of the dividing isthmus, which we know had already become extremely narrow, since deposits of the older seas actually overlapped each other in the Isle of Wight. The succeeding Upper Bagshot Sands belong to the same period, and, as already remarked, do not necessarily indicate change."

The succeeding sands indicate a shallowing of the water, which appears to have been produced by upheaval, the sea spaces over France and England being narrowed, till only the deeper portions remained to form the estuaries of the great rivers, and to receive the estuarine strata of the Oligocene series.

While the changes above described were taking place in the south-east of England, a very different set of materials was being accumulated in the north-western part of the British area, which was the scene of tremendous volcanic eruptions (see p. 454). Sheets of basaltic lava were poured forth from several volcanoes, and spread over a region of more than 200 miles in length, lying between the western highlands of Scotland and the outer Hebrides, and stretching southwards into the north of Ireland. Mr. J. S. Gardner has not yet completed his study of the leaf-beds which are intercalated between some of these lava-flows, but he has recently announced that he was arriving at the conclusion that they extend over a considerable period of time, commencing at a date anterior to any of our Lower Eocene beds, and coming down to the epoch of the Middle Eocene.

The denuded stumps of some of the volcanoes which poured forth these great streams of lava still exist in Skye, Mull, Rum, St. Kilda, and Ardnamurchan. The volcanoes of Skye and Mull appear to have been on a grander scale than the modern volcanoes of Italy; Professor Judd estimates that the base of the Mull volcano must have been at least 40 miles in circumference, and as Etna, from a base of only 30 miles in circumference, rises to a height

of 10,900 feet above the sea, he argues that if there was a similar relation between the base and the altitude of the Eocene volcano, the latter must have had an elevation of at least 14,500 feet. Checking this by another calculation, founded on the inclination of the lava-beds, he finds that it could not have been less than 10,000 feet high. To this height must be added the probable elevation of the inland tract above the Eocene sea, and this may have been between 2,000 and 3,000 feet, for it seems certain that Britain was united to North America by way of the Faroe Islands, Iceland, and Greenland; and to effect such a union between Scotland and Iceland now would require an elevation of 500 fathoms.

The Eocene plant remains found in Iceland and Greenland prove this northern continent to have had a temperate climate, and this means of communication explains the close connection that exists between the American and European Eocenes, both as regards vegetable and animal life.

**Oligocene Times.**—At the close of Eocene time the geography of the British area seems to have been as follows:—there was sea to the eastward spreading over Belgium and a large part of the German Ocean, and a smaller shallower sea lay over the south of England and the north of France, communicating probably with the Belgian sea by a strait between the Wealden ridge and the Ardennes, though of this there is no certainty. The coasts of this inner sea were low and swampy, and were backed by extensive tracts of low-lying or gently undulating ground, diversified by forests, lakes, and open plains, and inhabited by a large fauna in which most of the modern classes and orders of animals were represented. To the west from Brittany, northward through Cornwall and Wales to the north of Ireland and Scotland, lay a region of hills and mountains, among which at least one large river had its origin; this river, of which mention has previously been made, emptied itself into the north-western extremity of the inner sea, its estuary lying over part of Hampshire.

The Headon Beds present us with a section through part of the delta of this river. The alternation of marine, brackish, and freshwater beds is due, partly, to the process

of subsidence and silting up, partly, perhaps, to change in the course of the river channel, but the northerly and easterly increase of the marine strata (Brockenhurst Beds) and the southerly increase of the freshwater limestones, are facts which prove the deepest part of the estuary to have lain to the north-east of the Isle of Wight, and to have trended from south-west to north-east through Hampshire into Wilts or Somerset, in which direction the embouchure of the great river probably lay.

From a study of the current-marks in the Oligocene Beds, Dr. Sorby has inferred the direction of the currents and of the prevailing winds, and has calculated the breadth of that part of the estuary of which the Isle of Wight was a portion; he estimates it to have been 15 or 20 miles wide, "yet the dimensions of the river were such as to keep the water in general more or less fresh, and must have been much greater than any now running in England."

The muddy flats of this estuary swarmed with *Cerithiadæ*, *Cyrenidæ*, &c., while the pools of the delta were peopled by species of *Planorbis*, *Limnæa*, *Paludina*, &c., the dead shells of which were swept down into the lower reaches of the river; crocodiles, gavials, and turtles abounded in its waters as in those of modern tropical rivers, and its banks seem to have been clothed with a luxuriant vegetation of reeds, ferns, and palms.

The same conditions prevailed during the formation of the Bembridge and Hempstead Beds, with local variations; thus, some portions of the Bembridge limestones contain freshwater shells in the lower part, and land-snails with their eggs in the upper part, indicating the complete drying up of the shallow lake, or "broad," over the bottom of which it began to form, and the number of these large tropical snails is so great, that, as Mr. Gardner observes, their presence in such quantity necessarily implies that there was a large and varied flora in the jungles adjacent to the water. This terrestrial surface, however, was eventually swept away by river-floods or inroads of the sea, and part of the area was covered by brackish water in which oyster-banks were accumulated.

Of the Hempstead Beds so small a portion remains that it is unsafe to draw any very definite conclusions from the

nature of these deposits, though Mr. Gardner considers that their contents indicate a certain diminution of temperature, and the passing away of the semi-tropical conditions which prevailed at the close of the Eocene and beginning of Oligocene times. The records of the Hampshire delta are here abruptly broken off, and we have no means of ascertaining the last phases of its history; we can only guess from the analogy of the French deposits that there was a gradual upheaval of the whole area, and that throughout the ensuing Miocene period England was united to France and Belgium, and formed part of the European continent.

While the changes above indicated were occurring on the borders of the marine area, sedimentation of a different kind was taking place in the contemporaneous lacustrine areas; whether such lakes existed on British ground we do not know, but many were scattered through the centre of Europe, in France, Switzerland, and Austria, and as Sir C. Lyell remarks, "the study of these regions possesses a peculiar interest, very distinct in kind from that derivable from the investigation either of the Parisian or English Tertiary areas."

In the case of the Auvergne lakes (*ante*, p. 472) the records are so complete and of such a striking nature, that it becomes no difficult matter to restore in imagination the scene which they must have presented in Oligocene times, and to trace the wonderful series of changes by means of which the lakes were drained, and the present features of the district were gradually developed; these changes, however, belong to a later period than that we are now dealing with, and the volcanic eruptions with which they commenced date probably from the ensuing Miocene period. The following is Lyell's picture of the Auvergne lakes in Oligocene times.[1]

"There was first a period when the spacious lakes, of which we may still trace the boundaries, lay at the foot of (granitic) mountains of moderate elevation, unbroken by the bold peaks and precipices of Mont Dor, and unadorned by the picturesque outline of the Puy de Dome, or of the

[1] "Students' Elements of Geology," first edition, p. 207.

volcanic cones and craters now covering the granitic platform. During this earlier scene of repose deltas were slowly formed; beds of marl and sand several hundred feet thick deposited; siliceous and calcareous rocks precipitated from the waters of mineral springs; shells and insects embedded, together with the remains of the crocodile and tortoise; the eggs and bones of water-birds, and the skeletons of quadrupeds, most of them of genera and species characteristic of the Miocene (Oligocene) period. To this tranquil condition of the surface succeeded the era of volcanic eruption, when the lakes were drained and when the fertility of the mountainous district was probably enhanced by the igneous matter ejected from below, and poured down upon the more sterile granite."

The volcanic outbursts appear to have been accompanied by a gradual upheaval of the whole district, in which the north of France and the south of England participated, though probably the vertical elevation was greatest in the central European tracts;[1] by this elevation the slope of the river-channels would be increased, and the erosive powers of the rivers correspondingly augmented, the effluent streams so deepening their channels that eventually the lakes were completely drained, and the rivers began to cut their way through the materials which they had formerly deposited in the lakes. This, however, was a long and gradual process, continued throughout the succeeding periods, and down to the present time.

[1] The ranges of the Alps and Pyrenees appear to date their existence as mountain chains from the Oligocene period.

## CHAPTER XII.

### ICENIAN SYSTEM.

THE newer Tertiary strata, or those which are more recent than the Oligocene, have so much in common, both as regards their mode of occurrence and the species of fossils which they contain, that they must be viewed as forming only one system, and even when so grouped together they hardly form a system comparable to those which preceded them.

The name Icenian was used in 1851 by Dr. S. P. Woodward as a synonym for the Crags or Pliocene Beds of England, and it has been proposed to extend the application of the name not only to the Pleistocene Beds which conformably overlie the Pliocene in England, but to the older crag-like deposits which occur in Belgium and France, and have close palæontological affinities with the typical Pliocene or Icenian strata. Where complete, therefore, the system is thus divisible:—

| | | |
|---|---|---|
| Icenian system. | Pleistocene. | Newer. |
| | | Older. |
| | Pliocene. | Newer stage. |
| | | Older stage. |
| | Miocene. | Newer stage. |
| | | Older stage. |

The Miocene of this system is the Upper Miocene of Lyell, and its type is found in the "Faluns" of the Loire Valley; this, though lithologically similar to our Crags, is said to contain 75 per cent. of species which no longer exist, whereas the number of extinct species in the Coralline Crag

of England was said at the same time to be only 31 per cent. Many species, however, formerly supposed to be extinct, have since been discovered to exist in the Atlantic Ocean, and the number of extinct species in the Coralline Crag is now supposed to be less than 20 per cent. The fauna of the Faluns has not yet been re-examined for the purpose of correcting the older estimate, but when this is done the percentage of extinct species will probably be reduced; it is uncertain how far we can rely upon the proportion of extinct species as a test of age, and it is certain that the fauna of the Faluns is much more closely related to that of the Pliocene series than it is to the Oligocene fauna of England or France. If any Falunian beds ever existed in Britain or Belgium, we might imagine that their stratigraphical relations to the older Pliocene would be similar to those which subsist between the older and newer Pliocene in the east of England.

The British representatives of this system are:—

| | | |
|---|---|---|
| Pleistocene. | Post-glacial Beds. | |
| | Glacial Beds. | Newer. |
| | | Older. |
| Pliocene. | Forest Bed group. | Newer Pliocene. |
| | Norwich Crag. | |
| | Red Crag. | |
| | Coralline Crag (Older Pliocene). | |

The Pliocene strata cover a considerable area in the eastern parts of Essex, Suffolk, and Norfolk, resting unconformably either on London Clay or on the Chalk. A small tract has also been discovered recently in the south of Cornwall.

The Pleistocene deposits have a much wider extension, and cover large areas both in England, Scotland, and Ireland, resting indifferently on all older rocks, hence they are often called Superficial or Drift Deposits.

### A. Miocene Series.

In western Europe there is a decided stratigraphical break between the Upper Oligocene and the marine Mio-

cene strata. The Calcaire de la Beauce and its equivalents form extensive plateaux in France, both to the north and south of the granitic bosses in the Limoges and Auvergne, stretching in fact to the very base of the Pyrenees, where the beds are tilted and disturbed; resting unconformably on these strata, and occurring in scattered patches over these plateaux, lie the more recent Miocene beds, consisting chiefly of soft loose and undisturbed sands and marls.

During the interval thus indicated the upheaval of the European area, which was noticed in the last chapter (p. 485), seems to have continued till the whole of France, together with the Netherlands and the British area, was raised into continuous land; this land supported ranges of mountains which attained a considerable height. Large parts of the Mediterranean area appear, however, to have been open sea, and the epoch of the Falunian Miocene was a time of partial depression, allowing the southern sea to encroach upon the shores of the Oligo-Miocene continent and permitting the great lake-basins in its interior to be once more filled with water. We are therefore presented with a repetition of thick lacustrine deposits in Switzerland and Germany, the Oligocene and Miocene deposits appearing in these areas to form a continuous succession, while the marine records of the period are more scanty and local, except in Austria, where they occupy a large tract of country between the Alps and the Carpathians. It is possible, therefore, that the Austrian series will be eventually regarded as exhibiting the most complete and typical succession of marine Miocene strata, just as the Alpine Trias must be taken as furnishing us with the marine type of that system.

### *Life of the Period.*

The plants and the molluscs which are found in Miocene rocks indicate a much warmer climate than now prevails in Europe; they mostly belong to existing genera, and are not greatly differentiated from the Oligocene forms.

Of plants 81 Oligocene species range into the Miocene, but no fewer than 475 species of plants were determined from Professor Heer in the Œninghen beds of

Switzerland alone. These include a vine (*Vitis teutonica*), plane-trees (*Platanus aceroides*), maples (*Acer trilobatum*), cinnamons, figs, elms, liquidambars, cypresses (*Taxodium* and *Glyptostrobus*), with a few *Proteaceæ*. Looking to the Miocene flora as a whole, Professor Heer remarks[1] that "increased prominence is given to the Japanese types by the abundance of camphor trees and *Glyptostrobi*; to the Atlantic element by the laurels; to the American types by the numerous evergreen oaks, maples, poplars, planes, liquidambars, *Robiniæ*, *Sequoiæ*, *Taxodia*, and ternate-leaved pines; and to the types of Asia Minor by the *Planeræ*, and a species of poplar (*Populus mutabilis*). The greatest number and the most important of the types of the Swiss Miocene flora belong, therefore, to a belt lying between the isothermal lines of 59° and 77° Fahr., and in this zone America is now the region which is most correspondent to the natural character of the Swiss Miocene land."

Of Mollusca the following are a few of the characteristic species found in French and Austrian beds:—

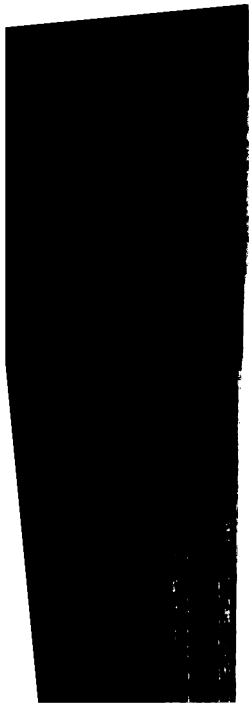
*Gasteropoda.*—Conus ventricosus, Murex plicatus, M. sublævatus, Trochus podolicus, T. punctulatus, Buccinum blesense, Voluta Lamberti.

*Lamellibranchs.*—Venus clathrata, Cardita affinis, Tapes gregaria, Pectunculus pilosus (glycimeris), Panopæa Faujasii, Pecten latissimus, Ervilia podolica.

It is, however, the Vertebrata and especially the Mammalia which are most distinctive of the period; the greater number of the older genera had become extinct, and a very different assemblage of animals had taken their place, *Acerotherium*, *Anchitherium*, and *Amphicyon* are almost the only animals that survived the change, unless certain beds in the Allier district, containing bones of *Tapir* and *Rhinoceros*, are properly classed with the Oligocene.

The important order of Proboscidea, which occupies such a prominent place throughout the whole of Icenian time, now appears for the first time, and is represented by the *Dinotherium* and the *Mastodon*. The former is remarkable for having two large tusks in the lower jaw (see fig. 118), which curve downwards, and are supposed to have been

[1] "Primæval World of Switzerland," transl. Heywood, vol. i. p. 371.



scoured over the plains.
also present, but the hor
with small canine teeth, is
*Machairodus* (the sabre-t
to the hyænas and civets),

Fig. 118. Skull of I

with otters, cats, and foxe
across the streams; a giga
tore up the ant-hill

ranean, supported large herds of antelopes and gazelles, varying in size and form, and for the most part allied to those of Africa.[1] With these were a species of giraffe and an animal of intermediate form between the giraffe and antelopes (*Helladotherium*). Numerous carnivores followed and preyed on these herbivorous animals—large cats and panthers (including *Machairodus*), *Hyœna*, *Ictitherium*, *Hyœnictis* (a form intermediate between *Hyœna* and *Ictitherium*), and *Simocyon* (an animal allied both to the wolf and the bear). It is not quite certain, however, that this Greek fauna is truly Miocene, for M. Gaudry, who first de-

Fig. 119. Restoration of Dinotherium giganteum.

scribed it, says that the ossiferous beds rest upon a marine deposit containing shells which are characteristic of Pliocene times; it depends, therefore, on whether we look to the Mollusca or the Mammalia as the best guides in Tertiary classification, and if the latter are taken, then the presence of *Dinotherium*, *Acerotherium*, *Hipparion*, and *Ictitherium* will stamp the beds as Miocene; but this association of Miocene mammals with Pliocene shells shows how close is the connection between the two series of deposits.

[1] Boyd Dawkins, "Early Man in Britain," p. 66.

*Stratigraphy.*

FRANCE.

**Basin of the Loire.**—The Faluns of Touraine was taken by Sir Ch. Lyell as the type of the Miocene in western Europe. "Faluns" is a local agricultural term applied to loose marly or shelly sands which, like the shelly "crag" of Suffolk, were formerly spread over the land for fertilizing purposes. The beds occur in scattered patches or tracts over a considerable length of country, extending from the mouth of the Loire to beyond Tours, and also along the banks of the Cher. They rest unconformably upon all older rocks, including the Calcaire de la Beauce, which, as mentioned on p. 472, forms the plateau between the valleys of the Seine and the Loire.

Sir Ch. Lyell describes the faluns as consisting generally of sand and sandy marl full of shells and corals, some entire, others rolled, and others in minute fragments, and the beds are seldom more than 50 feet thick; sometimes, as at Doué, near Saumur, "they form a soft building-stone, chiefly composed of an aggregate of broken shells, bryozoa, corals, and echinoderms, united by a calcareous cement, the whole mass being very like the Coralline Crag of Suffolk," to be described on a later page.

The fossil contents are those of a shallow but very warm sea; according to Edward Forbes they imply that the beds were accumulated between low-water mark and a depth of ten fathoms. *Cardita affinis*, *Cardium turonicum*, and *Venus clathrata* occur, with *Voluta Lamberti*, seven species of *Cypræa* and eight of *Conus*, some of them being much larger than any living Mediterranean cowry or cone; species of *Oliva*, *Ancillaria*, *Mitra*, *Terebra*, *Pyrula*, *Murex*, *Fasciolaria*, and *Nerita* are present, so that the assemblage is decidedly tropical. The bones of extinct Cetacea are occasionally found together with remains of the terrestrial mammalia—*Dinotherium*, *Mastodon*, *Rhinoceros*, *Hippopotamus*, and *Deer*.

**Brittany and Normandy.**—Small patches of faluns occur still further north, near the towns of Dinan, Rennes,

and in the Cotentin district; M. Dollfuss describes the Cotentin faluns as a soft calcareous rock, often entirely composed of rolled organic debris (Crustacea, Molluscs, Bryozoa, and Echinoderms), cemented by a whitish granular paste. Some beds are very hard, others soft and pebbly, with grains of quartz and fragments of the neighbouring rocks; the thickness is not more than 20 feet, and they are known to overlie the local Oligocene limestone. Excepting Bryozoa, the fossils which can be identified are few, but the general facies is that of the Faluns of the Loire; it is quite possible, however, that the deposit is of somewhat newer date than the southern Miocenes.

**Basin of the Garonne.**—Near Bordeaux, and southward to the base of the Pyrenees, large tracts of the country are overspread by beds of Oligocene age, and upon these lie scattered patches of faluns like those of Touraine, and near the base of the Pyrenees in Gers and Haute Garonne are tracts of freshwater marl, limestone, lignite, and sand, from which many interesting mammalian remains have been obtained, especially the apes (*Dryopithecus* and *Pliopithecus*), the former receiving its name from the oak-trunks with which it was associated.

**Basin of the Rhone.**—Yet another tract of Miocene strata has been discovered at Cucuron and Mont Leberon in Vaucluse, and this has yielded bones of *Hipparion*, *Helladotherium*, *Dinotherium*, *Rhinoceros*, *Tragoceras* (a small deer with bifurcating antlers like the Muntjak of tropical Asia), *Cervus*, *Gazella*, *Ictitherium*, *Hyæna*, and *Machairodus*.

### Switzerland.

The greater part of the low country lying between the Jura and the Alps consists of Oligocene and Miocene strata, and the Oligocene beds described on p. 474 are succeeded by the following groups in ascending order:—

**Mayence Group**, or Grey Molasse, sandstones with remains of terrestrial plants, and including an intercalated marine band with *Murex plicatus*, *Venus clathrata*, and *Cerithium lignitarium*.

**Helvetian Group**, marine sandstones and calcareous

conglomerates, with *Conus ventricosus*, *Pectunculus glycimeris*, *Panopæa Faujasii*, &c., 37 per cent. of the species being recent Mediterranean or tropical forms.

**Œninghen Group**, a freshwater formation, consisting of sands, marls, and limestones, with seams of lignite.

The Œninghen beds have yielded an immense number of plant and insect remains to the researches of Professor Heer, who records no less than 500 species of plants, and between 800 and 900 species of insects. The flora contains a mixture of generic forms which are now characteristic of widely separated countries. American forms predominate; next in number stand modern European genera; with these are some Asiatic types, and a few *Proteaceæ*, an order which now flourishes in South Africa and Australia. Among insects wood-eating beetles are particularly abundant. With these are remains of fish and freshwater tortoises, a huge salamander (*Andrias Scheuchzeri*), which was taken for a human skeleton when first discovered; also bones of *Dinotherium giganteum*, *Mastodon tapiroides*, *Palæomeryx eminens* (a ruminant), *Galecynus Œningensis* (a fox having affinities with the civet-cat), hares, beavers, and many small carnivores.

### Austria.

Miocene rocks cover a large area in Austria, and attain a thickness of over 1,000 feet in some places. The succession in the Vienna basin is as follows in ascending order:—

1. **Aquitanian Stage.**—A group of marls and sandstones, partly marine and partly freshwater, with seams of brown coal; by some referred to the Oligocene, because the marine beds contain *Cerithium plicatum* and *C. margaritaceum*, but the freshwater beds yield vertebrate remains of characteristic Miocene species—*Mastodon angustidens*, *M. tapiroides*, *Rhinoceros sansaniensis*, *Amphicyon intermedius*, and *Anchitherium aurelianense*.

2. **Mediterranean Stage.**—A variable set of strata, limestones, marls, clays, and sands, representing different conditions of deposit in various parts of the basin, but all purely marine; one of the most conspicuous formations is the Leithakalk, a highly fossiliferous limestone with

large Pectens (*P. latissimus*), Oysters, Clypeasters, Corals, and Bryozoa. The limestone, however, frequently passes into marl, sand, and even into conglomerate.

3. **Sarmatian Stage.**—Sandstones and sandy clays, containing an abundance of shells, but hardly any Corals, Echinoderms, or Bryozoa; the fauna has some affinities with that of the Black Sea, and is believed to indicate a similarity of geographical conditions,—namely, a narrow communication with the Mediterranean Sea, and the influx of large rivers producing a diminution in the saltness of the water. Some of the shells are *Tapes gregaria, Mactra podolica, Ervilia podolica, Cerithium pictum, C. rubiginosum,* and *Murex sublævatus.*

4. **Congerian Stage.**—Consisting of a pure clay, often 300 feet thick, deposited apparently in an inland sea like the Caspian; the commoner shells belong to the genera *Congeria, Cardium, Unio,* and *Melanopsis.* The mammals are Miocene species, and the plants resemble those of Œninghen.

## B. Pliocene Series.

Sir Charles Lyell divided the Pliocene series into an older and a newer stage, the former having from 30 to 50 per cent. of extinct species, and the latter less than 20 per cent.; and though these percentages are not perhaps strictly correct, yet the division into two stages may still be useful. If it is adopted, however, the Red Crag must be placed in the newer division, for many of the extinct species which it contains are in all probability extraneous fossils washed out of the Coralline Crag, and must therefore be excluded from the indigenous fauna; recent estimates give the proportion of extinct species of mollusca as less than 10 per cent. The number of extinct species in the Norwich Crag is only 11 out of 173 given by Mr. H. B. Woodward, *i.e.* 6.3 per cent.[1]

The term Upper Crag has been used by the Geological Survey to include the Red and Norwich Crag, with all their local variations, in contrast to the Lower or Coralline Crag, which is the only representative of the Older Plio-

[1] "Geology of the Country around Norwich, Mem. Geol. Survey."

cene in Britain, so far as is yet known, unless the sands capping the Chalk of the North Downs in Kent and Surrey belong to the same division of the Pliocene series.

*Life of the Period.*

Very few of the Invertebrate fossils belong to extinct genera, and the majority of the species are either identical with, or only varieties of, those now living. Among the Vertebrates, however, the majority of the species are extinct, and a few belong to extinct genera, such as *Mastodon*, *Trogontherium*, *Balænodon*, and *Halitherium*. The Pliocenes of France and Italy are characterized by *Mastodon arvernensis*, *Rhinoceros megarhinus*, *Rh. etruscus*, *Elephas meridionalis*, *Hippopotamus major*, *Cervus cusanus*, *C. Perrieri*, *C. pardinensis*, with *Machairodus cultridens*, *Hyæna striata*, bears, and wolves. Many of these occur also in Britain. The following are some of the fossils found in the British beds :—

## Fossils of the Coralline Crag.

*Corals.*—Cryptangia Woodii, Flabellum Woodii.

*Echinoderms.*—Temnechinus excavatus, Echinus Woodwardii, Brissus Scillæ.

*Polyzoa.*—Eschara monilifera, E. porosa, Biflustra delicatula, Fascicularia aurantum, Cellepora coronopora.

*Brachiopoda.*—Terebratula grandis.

*Lamellibranchs.*—Artemis exoleta, Astarte Omalii, A. Burtini, Cardita senilis, Cyprina rustica, Isocardia cor, Tellina crassa, Pecten opercularis, Panopæa Faujasii, Venus casina.

*Gasteropoda.*—Buccinum Dalei, Turritella incrassata, Natica multipunctata, Fusus gracilis, Voluta Lamberti, Trochus zizyphinus, Cassidaria bicatenata.

*Mammalia.*—Balæna mysticetus, Balænodon physaloides, with teeth of Mastodon arvernensis, Rhinoceros Schleiermacheri, and Cervus dicranoceras.

## Fossils of the Red Crag.

*Corals.*—Balanophyllia calyculus.

*Echinoderms.*—Temnechinus turbinatus, Echinocyamus pusillus.

*Polyzoa.*—Flustra distans, Hippothoa dentata.

*Brachiopoda.*—Rhynchonella psittacea.

*Lamellibranchs.*—Pecten opercularis, Pectunculus glycimeris, Mactra ovalis, M. constricta, Cardium angustatum, Astarte obliquata.

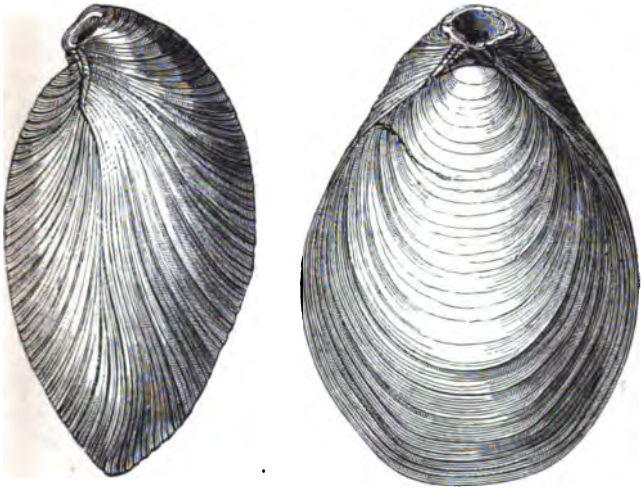


Fig. 120. Terebratula grandis, natural size.

*Gasteropoda.*—Nassa reticosa, Purpura tetragona, Trophon antiquum, Tr. elegans, Scalaria grœnlandica, Natica hemiclausa, Columbella sulcata.

*Mammalia.*—Phocœna orca, Balænodon affinis, B. emarginata, Halitherium Canhami, Hoplocetus crassidens; and the terrestrial forms—Elephas meridionalis, Hyæna striata, Cervus Suttonensis, Mastodon arvernensis, Rhinoceros incisivus, Tapirus arvernensis, Hipparion sp., Felis pardoides, and two species of Pigs.

## Fossils of the Norwich Crag.

*Lamellibranchs.*—Astarte compressa, A. borealis, Cardium edule, Cyprina islandica, Nucula Cobboldiæ, Tellina obliqua, T. lata, Mya arenaria, Scrobicularia plana.

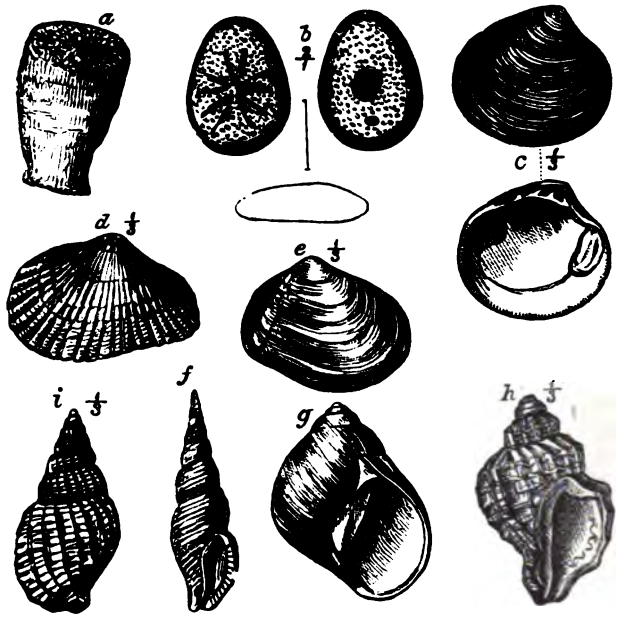



Fig. 121. Fossils of the Red Crag.

*a.* Balanophyllia calyculus.
*b.* Echinocyamus pusillus.
*c.* Astarte obliquata.
*d.* Cardium angustatum.
*e.* Mactra constricta.
*f.* Columbella sulcata.
*g.* Natica hemiclausa.
*h.* Purpura tetragona.
*i.* Nassa reticosa.

*Gasteropoda.*—Litorina litorea, Purpura lapillus, Cerithium tricinctum, Natica catena, Turritella communis (terebra).

*Mammalia.*—Elephas antiquus, E. meridionalis, Cervus

elaphus, Cervus ardens, Trogontherium Cuvieri, Arvicola intermedius, Mastodon arvernensis, Felis pardoides, Hippopotamus major, Hyæna striata.

## Fossils of the Forest Bed.

As authorities differ on the question whether this group of beds should be regarded as the summit of the Pliocene series or the base of the Pleistocene, it is desirable to review the fauna and flora, to which the recent researches of Messrs. C. Reid and E. T. Newton have added many species.[1]

The flora indicates a climate very similar to that now prevailing in Norfolk, and only two species no longer live in Britain, viz., *Pinus abies* (the spruce-fir) and *Trapa natans* (a pond plant).

Of the marine Mollusca all occur both in the Weybourne Crag and in later Pleistocene deposits, so that they afford no guide.

The only remaining test is that of the Mammalia, and when these are arranged in three groups, as below, it is seen that they prove the beds to have been formed just at the epoch of transition from Pliocene to Pleistocene time, a certain number being survivals from the Pliocene (either of Britain or France), and about an equal number being new-comers which range to Pleistocene or to modern times; while a few have not yet been found elsewhere.

(1.) *Survivals from Pliocene*, 17.

Mastodon arvernensis.
Elephas meridionalis.
„ antiquus.
Rhinoceros etruscus.
„ megarhinus.
Hippopotamus major.
Equus stenonis.
„ caballus (Horse).
Ursus arvernensis.
Cervus dicranios.
„ polignacus.
„ Etueriarum.
„ elaphus (Stag).
Machairodus latidens.
Trogontherium Cuvieri.
Castor europæus (Beaver).
Arvicola intermedia.

[1] See "Geology of the Country around Cromer, Mem. Geol. Survey," 1882.

(2.) *New-comers ranging to newer beds*, 21.

Elephas primigenius (Mammoth).
Bos primigenius (The Urus).
Ovibos moschatus (Musk-ox).
Cervus megaceros ? ? (Irish Elk).
Ursus spelæus (Cave-bear).
„ ferox (Grizzly Bear).
Gulo luscus (Glutton).
Canis vulpes ? (Fox).
„ lupus ? (Wolf).
Martes sylvatica (Marten).
Sus scrofa (Wild Boar).
Myogale moschata (Musk-shrew).
Sorex vulgaris (Shrew).
„ pygmæus (Pigmy Shrew).
Talpa europæa (Mole).
Mus sylvaticus (Mouse).
Arvicola arvalis (Field Vole).
„ gregalis.
„ amphibius (Water Vole).
„ glareolus (Red Vole).
Sciurus vulgaris ? (Squirrel).

(3.) *Species not known elsewhere.*

Caprovis Savinii.
Cervus verticornis.
„ latifrons.
„ Gunnii.
Cervus Fitchii.
„ carnutorum.
„ Dawkinsii.
„ bovides.

Fig. 122. Lower jaw of Trogontherium Cuvieri, an extinct kind of beaver (half natural size).

Of the twenty species which range into higher beds four are named from specimens about the origin of which there is some doubt, and some of the others, such as *Canis vulpes*, *Sus scrofa*, and *Arvicola arvalis*, have been recorded from the Norwich Crag with a similar amount of uncertainty. The only really arctic species is the Glutton (*Gulo luscus*). It should be mentioned, however, that some of the Pliocene survivals range into the Pleistocene.

Among freshwater Mollusca a few are extinct in Europe, viz. :—*Pisidium astartoides, Corbicula fluminalis, Paludina gibba*, and others only now live on the Continent, *e.g.*, *Lithoglyphus fuscus, Hydrobia marginata, H. Steinii*, and *Valvata fluviatilis*.

### *Stratigraphy.*

#### Britain.

**Coralline Crag.**—This crag is only found over a small area in Suffolk, between Aldborough and Tattingstone, and is exposed in several small isolated tracts at these places, and at Orford, Sudbourn, Iken, and Sutton. It rests on an eroded surface of the London Clay, and its basement bed contains a remarkable assemblage of materials derived from older deposits, and chiefly from the London Clay; the pebbles are chiefly phosphate nodules of a dark-brown colour, but with these are fragments of septaria, a few small pebbles of quartz and flint, and some nodules or balls of coarse dark-brown sandstone often containing the cast of a shell, and known as box-stones; a rounded boulder of dark-red porphyry also occurred in this bed at Sutton; with these are Crustacea and Fish-teeth derived from the London Clay, Saurian vertebræ from the Oxford Clay, mammalian teeth of doubtful age, and many Cetacean bones and teeth.

The fossils in the Box-stones correspond with those of the Diestien or Black Crag of Antwerp (see p. 509), and it is probable therefore that deposits of this age previously existed in the vicinity, but were destroyed by the encroachments of the sea during the formation of the crags; these stones are abundant also in the similar nodule bed at the base of the Red Crag.

Above the nodule bed there are yellowish marly sands and fine sharp sands, with layers of comminuted shells, from 30 to 40 feet thick, and these form the lower division of the Crag; above them at Sutton, Gedgrave, and Aldborough come about 30 feet of a soft porous yellowish-brown calcareous rock, consisting almost entirely of comminuted shells and fragments of Polyzoa, which are often

arranged in oblique laminæ, while the bedding is of that irregular kind due to the action of rapid and changeable currents. This soft limestone forms the upper division of the Coralline Crag. Fossils are abundant in both divisions, but the assemblages are often rather different.

The mollusca of the Coralline Crag indicate a sea of some depth (90-100 fathoms), and warmer than the neighbouring sea; out of 264 species which are identical with recent forms, 200 are living in the Mediterranean, and only 185 on British coasts, seventeen being species peculiar to the Mediterranean and fourteen to the Atlantic Ocean.[1]

**Red Crag.**—This formation covers a much larger area than the older (Coralline) crag, and is apparently continuous over a space of 300 or 400 square miles in Suffolk, but is so often concealed by the sands and clays of the Glacial series, that generally it is only on the slopes of the valleys which intersect the district that the crag actually comes to the surface. The best exposures occur in the valleys of the rivers Orwell and Deben, and in the cliff-sections of Felixstow and Bawdsey.

The Red Crag rests partly on the London Clay and partly on the Coralline Crag, wrapping round the isolated reefs of the latter, filling up the hollows between them, and often lying nearly on a level with the older crag.

Professor Prestwich remarks, "whilst the Coralline Crag consists essentially of light-coloured calcareous beds with an admixture of siliceous sand, the Red Crag consists of a base of siliceous sands, with more or less of the peroxide of iron, and a few thin seams of clay. They form such an extremely variable series that I have failed to observe any definite order of succession in the various beds of the lower series, or to recognize the 'beach-stages' of Mr. S. V. Wood, jun. I would divide them into two groups only, the lower one characterized by the prevalence of oblique lamination, without permanent or definite order of succession in the beds, and the upper by more persistent horizontal bedding. Shells abound in the lower, and are rarer in the upper division."[2]

[1] For note on the Kentish Sands see Appendix B.
[2] "Quart. Journ. Geol. Soc.," vol. xxvii. p. 325.

In the central area there is generally a basement bed of phosphatic nodules (the so-called coprolites) like that at the base of the Coralline Crag, and containing a similar assemblage of derived stones and fossils,—flints from the Chalk, septaria from the London Clay, "box-stones" from the Diestien Crag, large pebbles of siliceous sandstone (? Tertiary), chert from the Lower Greensand, and a fragment of red granite; with these are rolled mammalian bones and teeth, and many of the larger contemporaneous shells, especially *Trophon antiquum*, *Voluta Lamberti*, *Cardium edule*, *Pectunculus glycimeris*, and *Cyprina islandica*. This basement bed sometimes thins out altogether, and in other places it divides into two beds separated by one or two feet of shelly crag.

The overlying current-bedded and shelly sands, which form the deposit known as the Red Crag, are generally 10 or 15 feet thick, but sometimes thicken to 20 or 25 feet. The upper beds are more evenly bedded and contain fewer shells than the lower.

The manner in which the Red Crag is sometimes banked against the Coralline Crag is illustrated in the section, fig. 123. In the pits near Sutton there is evidence of two shore-levels, an upper and a lower cliff-line, implying a submergence of 9 or 10 feet between the epochs of their formation.[1] The upper cliff is about 12 feet high, and must formerly have been higher, as blocks of a hard bed capping the hill above are found at its base, and some of them weigh more than a ton. With these blocks are flints and coprolites and shells of *Mytili*, while the surface of the Coralline Crag is perforated by *Pholas*-borings. The lower shore-line is about 9 feet below the upper, and here again derived blocks, coprolites, and *Mytili* were found. These two shore-lines are traceable all round the mass of Coralline Crag, which is intersected by the section, fig. 123, and which evidently formed a reef in the Red Crag sea.

At St. Erth, near Hayle, in Cornwall, and at an elevation of about 100 feet above the sea-level (Ordnance datum), there is a deposit of clay containing a number of shells

[1] Prestwich, loc. cit., p. 340.

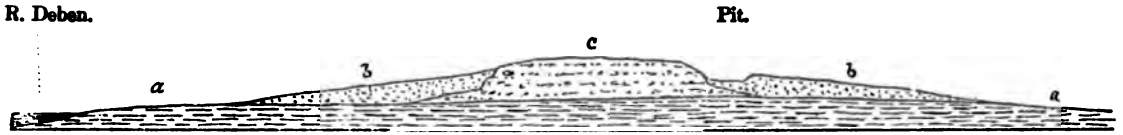



Fig. 123. Section near Sutton in Suffolk (after Professor Prestwich).
Distance about half a mile.

*a*. London Clay. *b*. Red Crag. *c*. Coralline Crag.

Fig. 124. Diagrammatic section from Fakenham to near Cromer, in Norfolk.
Distance about 18 miles.

*a*. Chalk.
*b*. Norwich Crag.
*c*. Cromer Till and Contorted Drift.
*e*. Sand and Gravel.
*f*. Chalky Boulder-clay.

which prove it to be of Pliocene age. The beds seen in a pit near the vicarage are:—

| | Feet. |
|---|---|
| Loamy clay, full of angular stones . . . . . | 2 to 6 |
| Fine gravel and coarse ferruginous sand . . . . . | 4 to 6 |
| Clay, yellow above, blue beneath, and containing many fossils | 6 |
| Fine foundry sand, base not exposed . . . . . | ? 10 |

The sand is probably about 10 feet thick, and is said to rest on a highly ferruginous sand, locally known as "growder," and this basement bed can be seen at a little distance resting on an Elvan dyke.

The fossils show a general agreement with the lower part of the Red Crag, but many species of a southern character are present, such as *Fusus corneus, Nassa reticostata, Nassa mutabilis, Cardium tuberculatum, C. papillosum, Cardium aculeata*, and *Nucula sulcata*, which do not occur in the eastern Crags, while the Boreal and Arctic forms found so abundantly in the Crags are absent at St. Erth. The following species link the deposit to the Red Crag, *Nassa serrata* (*reticosa*), *Columbella sulcata, Litorina suboperta*, and *Conovulus pyramidalis*, these being either confined to or specially abundant in that deposit. Altogether about 80 species have been obtained from this clay.[1]

**Norwich Crag.**—This group has a more extended range than either of the older crags, since it is found at intervals from the valley of the Orwell, in Suffolk, to Weybourne, on the north coast of Norfolk, a distance of between 60 and 70 miles. It is well exposed at many localities in the neighbourhood of Norwich, whence it takes its name; it is described as a variable group of sands, laminated clays, and pebbly gravels, with occasional seams or patches of shells, and different local names were given to different portions of the group before it was ascertained that they all belonged to one division of the Crag.

Thus in Suffolk, where it rests indifferently on the Red or Coralline Crags, the laminated clays and fossiliferous sands are known as the "Chillesford or Aldeby Beds,"

[1] See papers by S. V. Wood, in "Quart. Journ. Geol. Soc.," vol. xli. p. 65, and by Messrs. Bell and Kendall, op. cit., vol. xlii.

while in Norfolk, where it rests directly on the Chalk, and has a basement bed of large flints and ferruginous gravel containing mammalian remains, the lower beds have been called the "Mammaliferous Crag," and the "Fluvio-marine Crag," the overlying laminated clays and sands have been termed "The Laminated Series," and the uppermost pebbly sands have been known as the "Bure Valley Beds," and also as the "Westleton Beds." Mr. H. B. Woodward remarks that though near Norwich there is such a general succession, as above indicated, yet none of the layers are persistent for any distance, the laminated clays being lenticular layers, or "jambs," and not forming a definite horizon to which the name Chillesford Clay could be applied.[1]

Fig. 125 shows the relative position of the three crag groups near Aldborough in Suffolk (after Professor Prestwich, loc. cit., p. 339).

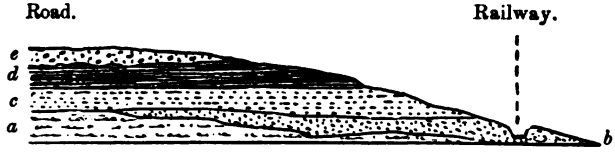



Fig. 125. Section by Warren House, N. of Aldborough. Height about 25 feet.

*e.* Sand and Gravel (Glacial).

*d.* Clay, *c.* Sand } Norwich Crag. *b.* Red Crag. *a.* Coralline Crag.

Fig. 124 shows the general position of the Norwich Crag in Norfolk, and the following are the beds exposed in one of the best sections near Norwich, viz. Thorpe Lime-kiln:—

| | | Feet. |
|---|---|---|
| Norwich Crag. | False-bedded sand and shingle, formed chiefly of flint and quartz, hardened in places into conglomerate | 8 to 12 |
| | False-bedded sand, with seams of sandy clay | 3 |
| | White and buff sands, with shell patches | 5 |
| | Rolled flints with pebbles, sand and shells and bones | 1 |
| Chalk, with flints, 20 feet shown. | | |

[1] "Geology of the Country around Norwich, Mem. Geol. Survey," p. 34.

This may be compared with the Cottishall section in the Bure Valley, which is as follows: [1]—

| | | Feet. |
|---|---|---|
| Norwich Crag. | False-bedded pebbly gravel and sand | 9 to 12 |
| | Laminated clay, with a bed of sand | 6 |
| | False-bedded sand, gravel, and shell-beds | 5 |

Chalk, with flints, 12 feet exposed.

The Crag of the Bure Valley contains two shells (*Tellina Balthica* and *Paludina vivipara*) which have not been found in the sections near Norwich, and Mr. S. V. Wood, jun., regarded all the beds containing the *Tellina Balthica* as newer than the Norwich Crag. Mr. Woodward, however, considers them and the Weybourne Crag (see p. 508) to belong to the same group, and remarks that even in beds which are acknowledged to be on the same horizon the relative abundance of the species varies greatly, species which are abundant at one locality being rare at others, and he gives several instances of this (op. cit., p. 36).

Near Norwich and in the Bure Valley the Norwich Crag has a general thickness of about 30 feet, but at Beccles it attains a thickness of 95 feet, exclusive of the uppermost pebbly division.

The Norwich Crag contains many northern forms of mollusca which do not occur in the Red Crag, the relative numbers of southern and northern species in the three Crags being as follows:—

| | Living species. | Northern. | Southern. |
|---|---|---|---|
| Norwich Crag | 130 | 19 | 11 |
| Red Crag | 216 | 23 | 32 |
| Coralline Crag | 264 | 14 | 65 |

Thus the percentage of northern species in the Coralline Crag is 5.0, in the Red Crag 10.7, in the Norwich Crag 14.6; in the Weybourne Crag it is 16 per cent.

**The Forest Bed Group.**—The highest members of the Pliocene series are exposed along the Norfolk coast between Weybourne and Happisburgh; they have been described by many writers, but the most recent and complete description

[1] Taken from Mr. H. B. Woodward's "Geology of the Country around Norwich, Mem. Geol. Survey."

is by Mr. C. Reid, of the Geological Survey,[1] who classifies them as follows :—

| | | Feet. |
|---|---|---|
| 5. *Leda myalis* Bed | | 4 to 15 |
| 4. Upper Freshwater Bed | Forest bed group | |
| 3. Forest Bed (estuarine) | | 10 to 20 |
| 2. Lower Freshwater Bed | | |
| 1. Weybourne Crag | | 1 to 12 |

The Weybourne Crag is regarded as part of the Norwich Crag group, the fauna differing only by having a slightly greater proportion of Arctic species and by including *Tellina Balthica*, which however occurs also in the Bure Valley beds.

In the Forest Bed three divisions are recognized by Mr. Reid, but the lower bed is a local and partial deposit, its relation to the central estuarine portion resembling that of more recent "submerged forests" to the mud of modern estuaries. The middle division consists of clay, sand, and gravel in irregular layers, and contains a mixture of marine and freshwater shells with many mammalian bones; it received its name of "Forest Bed" from the frequent occurrence of stumps, logs, and matted roots of trees, but these are not in the position of growth, as formerly supposed; they have all been drifted, though probably not from any great distance, and from the appearances presented by many of the stumps Mr. Reid concludes that they have grown on the side of a steep river-bank which was continually being undermined and washed away by the current, "and settling generally in an upright position as we should expect from the greater density of the roots, and from the weight of the adhering soil, they have formed 'snags' in the river, such as are constantly met with in streams flowing through a forest-clad country."

The upper surface of the "Forest Bed" is often weathered into a soil and penetrated by small roots (hence termed the Rootlet Bed), and is in some places covered by lacustrine deposits containing freshwater shells, with remains of fish, amphibia, and small mammalia; this is the upper freshwater bed.

[1] "Geology of the Country around Cromer, Mem. Geol. Survey," 1882.

The *Leda myalis* bed is a fine current-bedded loamy sand, with thin seams of loam and gravel. The fossils are marine, and indicate a depth of 5 or 10 fathoms, as some of the bivalves occur with the valves united in the position of life. All the mollusca yet found (19 species) occur in the Weybourne Crag, and they include two characteristic crag shells, *Trophon antiquum* and *Tellina obliqua*. One of the best exposures is at Runton Gap, near Cromer, where *Leda myalis*, *Mya arenaria*, and *Astarte borealis* may be found in position of life, and the bed is 15 feet thick. South of Cromer it either thins out, or is cut off by the Glacial Beds.

### Belgium and France.

**Belgium.**—In the neighbourhood of Antwerp there is a series of crag-like deposits, some of which are comparable to our Crags, and but the lowest are clearly of older date, and exhibit affinities with the Faluns of France; these have been termed Miocene by some authors, Mio-Pliocene by others, but it will be convenient to describe them in the present connection. The complete succession is as follows:—

| | |
|---|---|
| 5. Sands with *Trophon antiquum*. | Pliocene. |
| 4. Sands with *Isocardia cor*. | |
| 3. Sands with Cetacean bones. | Mio-Pliocene or Diestien. |
| 2. Sands with *Pectunculus pilosus*. | |
| 1. Sands with *Panopœa Menardi*. | |

(1) The sands with *Panopœa Menardi* rest on the Rupelian Clay (Oligocene), and have at their base a pebble bed containing rolled blocks of septaria derived from that clay, and often pierced by *Pholas* borings; above are 9 or 10 feet of grey and somewhat clayey sand full of shells, among which, besides *P. Menardi*, are *Murex Nysti*, *Conus Dujardini*, *Pleurotoma interrupta*, *Astarte radiata*, *Cardita intermedia*, *Venus multilamella*, *Saxicava arctica*, and *Lucina borealis*. (2) Above this are dark glauconitic sands, with *Pectunculus pilosus*, *Ostrea navicularis*, *Pecten Caillaudi*, and some of the same species occurring in the bed

below. (3) At the summit there is generally a layer of pebbly green sand, containing sharks' teeth, Cetacean bones, and some of the same shells.

Overlying the group above described are beds (4) which contain a fauna similar to that of our Coralline Crag. At the base is a pebble bed covered by a blackish sand yielding sharks' teeth, *Cyprina rustica*, and *Cardita senilis*, and this passes up into pale greenish-grey sand, from which above 60 species of shells have been obtained, the most abundant being *Isocardia cor*, *Astarte Omalii*, *Lucina borealis*, *Ringicula buccinea*, and *Turritella incrassata*, with bones of *Balæna* and *Balænoptera*.

Resting on the eroded surface of No. 4 are red and grey sands similar to our Red Crag, and containing many of the same shells, especially *Trophon antiquum*, *Tr. gracile*, *Voluta Lamberti*, *Nassa reticosa*, *N. labiosa*, *Purpura tetragona*, *Pecten maximus*, and *P. Gerardi*. No newer Pliocene beds comparable to the Norwich Crag have yet been found in Belgium.

**France.**—Space will not allow us to review all the Pliocene deposits of France, and still less to notice those of Austria, Italy, and Greece. Those of the Cotentin in Normandy and of the Auvergne are selected for description.

In Normandy the Pliocene beds, overlying the Faluns mentioned on p. 493, are divisible into two stages:—

2. Marnes à *Nassa*.
1. Conglomerat sableux à *Terebratula grandis*.

The lower of these is a ferruginous sandy gravel, from 15 to 20 feet thick, and has yielded at Courbeville 143 species of fossils, of which 105 occur in our Crags, equal numbers (namely 99) being common to the Coralline and the Red Crag; hence it would appear to represent the lowest part of the Red Crag, or possibly the interval between that and the Coralline Crag. The Marnes à *Nassa* consist of grey or greenish marl, sometimes argillaceous and sometimes calcareous matter predominating, and the thickness varies from 15 to 20 feet; *Nassa limata* is the commonest shell, and out of 53 species 28 occur in our

Red Crag, 22 in the Norwich Crag, and 13 in the St. Erth beds.

In Auvergne, at Perrier and elsewhere, fluviatile and lacustrine deposits occur above the lava-flows which destroyed the Oligocene lakes, but are themselves covered by newer sheets of lava and volcanic ash. These beds have yielded bones of *Mastodon arvernensis*, *Rhinoceros megarhinus*, *Elephas meridionalis*, *Hippopotamus major*, and a number of peculiar deer—*Cervus cusanus*, *C. Perrieri*, *C. etueriarum*, *C. pardinensis*, and *C. tetraceros*; with these are many beasts of prey, extinct species of tigers (*Machairodus*), panthers, lynxes, bears, wolves, and hyænas.

## C. Pleistocene Series.

The term *Pleistocene* was used by Sir Ch. Lyell to denote such deposits as were newer than the Pliocene, and yet not modern enough to be called Recent, and he grouped both the Pleistocene and Recent deposits under the head of *Post-Tertiary*. This last term, however, is undesirable, because it implies a distinction and separation from Tertiary which does not exist. The same objection holds with regard to the synonym *Quaternary*, which is much used on the Continent and in America.

I have consequently followed the example of Professor Jukes, and take Pleistocene to include all the deposits that have been formed from the close of the Pliocene down to the present time. In England these deposits may be conveniently divided into Glacial and Post-Glacial Beds, but Professor Dawkins has pointed out that the Glacial epoch must be regarded as a special episode or phase of Pleistocene times, the influence of which was limited to certain parts of the earth's surface; he proves, moreover, that the transition from Pliocene to Pleistocene time is marked by a change in the mammalian fauna of Europe, and consequently that it is the introduction of this fauna, and not the first commencement of glacial conditions, which marks the beginning of Pleistocene time. The Glacial period did not define one fauna from another, but only modified the range of certain species, limiting that of

the southern forms and extending that of the northern forms, during its continuance.

### *Life of the Period.*

The Glacial deposits contain but very few traces of life, though remains of the Mammoth (*Elephas primigenius*) and the Reindeer (*Cervus tarandus*) have been found in the so-called inter-glacial beds of Scotland; while *Elephas antiquus*, *Rhinoceros leptorhinus*, and *Bos primigenius* have been found in gravel beneath the uppermost Boulder-clay in Lincolnshire.

The Mollusca of Pleistocene times all belong to living species, but those found in the marine Glacial deposits are such as live in the seas round the northern parts of our islands, the species of our southern coasts being generally absent. The following are some of the commoner species in Glacial beds:—

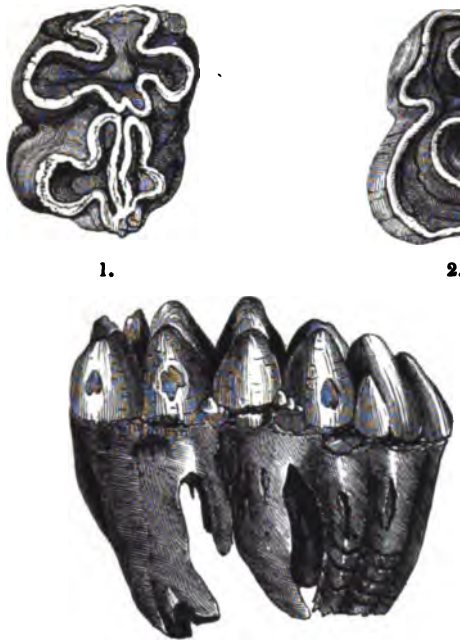
*Gasteropoda.*—Natica clausa, Trophon clathratum, Buccinum undatum, B. grœnlandicum, Pleurotoma turricula, Turritella terebra.

*Lamellibranchs.*—Pecten islandicus, Leda truncata, L. lanceolata, Tellina calcarea, T. balthica, Astarte borealis, A. compressa, Panopæa norvegica, Saxicava rugosa, Cyprina islandica.

The mammalian fauna of the period is principally known from the remains preserved in the caves and river-gravels of southern and central England, some of which may possibly be contemporaneous with the later Glacial deposits of the more northern districts; there is at any rate little doubt that the fauna of the older river-gravels is that which existed on the European continent during the Glacial epoch.

Professor Dawkins remarks that "the remarkable association of animals in Pleistocene Europe, some of which are now only alive in widely remote parts of the world, points with unerring certainty to great geographical and climatal changes. Nearly all the temperate, northern, and mountainous species can be traced to northern and central Asia," and to account for this immigration he

supposes that a low-lying tract of country between the Caspian and the Gulf of Obi, which had probably hitherto been the bottom of a shallow sea, and had prevented any earlier migration, was now elevated, and allowed of their



1. 2.

3.

Fig. 126. Mammalian Teeth.

1. Hippopotamus major (½). 2. Rhinoceros leptorhinus (½). Mastodon Ohioticus (⅛).

passage into Europe. The concomitant lowering of the temperature gave an impulse to this migration; "as the cold increased in Asia, and the warm Pliocene climate of northern and central Europe gradually became cool, the animals which had been living in Asia for an unknown

series of years poured in by the way now opened for them."[1]

From the list of Forest Bed mammals given on p. 500, it will be seen that this immigration of Arctic and temperate Asiatic species had commenced at that time, and that many of them had reached the British area; that bed was evidently formed just at the time of transition from Pliocene to Pleistocene conditions, but as the Pliocene fauna had

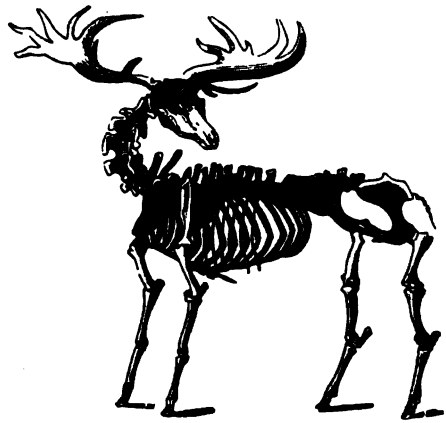


Fig. 127. Skeleton of Cervus megaceros.
The original about 10 feet high.

not then been wholly displaced, and many characteristic Pliocene species still remained in Britain, it is convenient to retain the Forest Bed in the earlier series.

The following is a list of the Pleistocene Mammalia:—

(1.) *Survivals from later Pliocene.*

Hippopotamus major.
Rhinoceros megarhinus.
Elephas antiquus.
" primigenius.
Bos primigenius.
Ovibos moschatus (Musk-ox).
Cervus elaphus (Stag).
Equus caballus (Horse).
Sus scrofa (Wild Boar).
Canis lupus (Wolf).
" vulpes (Fox).
Martes sylvatica (Marten).

[1] "Early Man in Britain," 1880, pp. 109, 121.

Machairodus latidens.
Ursus ferox (Grizzly Bear).
„ spelæus (Cave Bear).
Gulo luscus (Glutton).
Castor europæus (Beaver).
Mus sylvaticus (Mouse).
Arvicola amphibia (Vole).
„ gregalis.
„ arvalis.
„ glareolus.
Sorex vulgaris (Shrew).

(2.) *New-comers in the older Thames Gravels.*

Rhinoceros tichorhinus.
„ leptorhinus.
Bison priscus (Bison).
Spermophilus catillus.
Ursus arctos (Brown Bear).
Felis leo (Lion).
Felis catus (Wild Cat).
Lutra vulgaris (Otter).
Hyæna crocuta (Spotted Hyæna).
Cervus megaceros (Irish Elk).
„ dama (Fallow Deer).
„ capreolus (Roe Deer).

Most of the above occur also in the later river-gravels and in the cave-deposits of England, but are accompanied by the following additional species :—

Felis lynx (Lynx).
„ pardus (Leopard).
„ caffer (Caffer Cat).
Mustela putorius (Stoat).
„ (Weasel).
Canis lagopus (Arctic Fox).
Meles taxus (Badger).
Cervus tarandus (Reindeer).
Myodes torquatus (Norway Lemming).
Myodes lemmus (Arctic Lemming).
Lepus variabilis (Mountain Hare).
Lagomys pusillus (Tailless Hare).
Arvicola ratticeps (Russian Vole).

Pleistocene deposits in other parts of the world have yielded many remarkable extinct species of Mammalia; thus in North America, besides the mammoth and other animals which lived also in Europe and Asia, there was a species of *Mastodon* differing from those of Miocene and Pliocene times in having tusks only in the upper jaw when adult, though the rudiments of the lower pair of tusks are found in the skulls of very young animals. Fig. 128 represents this *Mastodon*, which seems to have lingered in North America to as late a period as the Irish elk and the Mammoth did in England.

In South America the Pleistocene fauna includes many gigantic progenitors of the animals which compose the peculiar existent fauna of that country. The leaf-eating sloths of the present day were thus preceded by gigantic Edentates—the *Mylodon* (11 feet long), the *Megatherium* (18 feet long), so well known from the skeleton in the

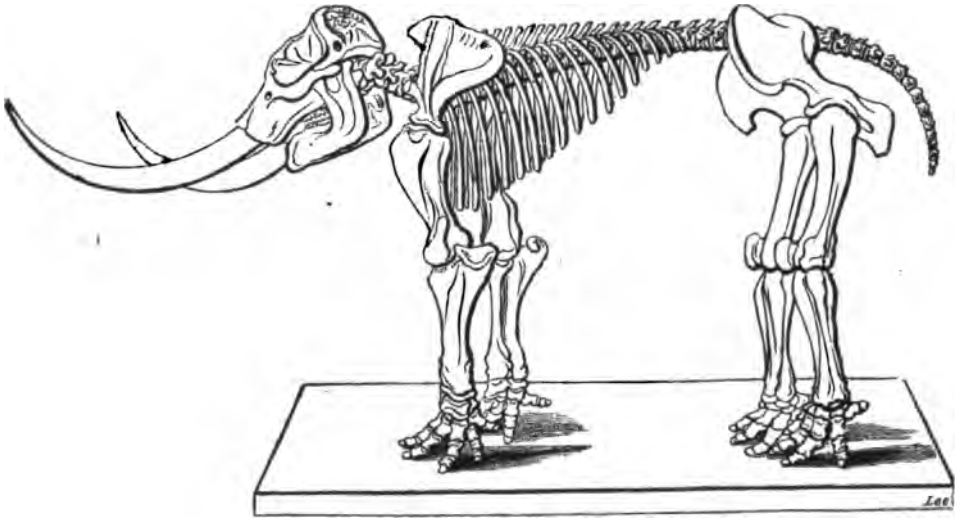


Fig. 128. Skeleton of Mastodon Ohioticus (North America).
Height 9½ feet, length 20 feet.

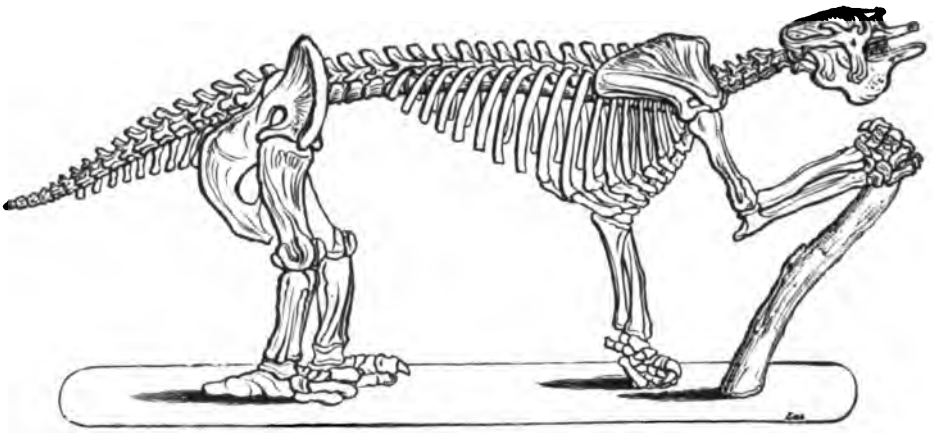


**Fig. 129. Skeleton of Megatherium Cuvieri (South America).**
**Height 8 feet, length 20 feet.**

British Museum (fig. 129), the *Megalonyx*, and the *Scelidotherium*. The armadillos were represented by the *Glyptodon*, whose curved back, with its tesselated coat of mail, measured 7 feet across, the whole animal from snout to end of tail probably measuring 9 or 10 feet. There were also extinct species of mastodon, opossum, tapir, peccary, llama, horse, platyrhine monkeys, and various carnivora.

The same is the case in Australia, where extinct species of Marsupials, and many of them gigantic forms, preceded those which now occupy the country; gigantic kangaroos and wombats, with animals (*Diprotodon* and *Nototherium*) which are intermediate between recent genera, were the prey of equally large carnivorous genera (*Thylacoleo*, &c.).

### *Stratigraphy.*

## a. Glacial Deposits.

The Glacial Beds are the relics of a period when the conditions which are now confined to the Arctic and Antarctic regions prevailed over the whole of northern Europe. The deposits accumulated during this period are principally such as result from the action of moving masses of ice (boulder-clays), or from the action of strong currents of water (coarse gravels), but interstratified with these there are sometimes sands, brick-earths, and laminated loams which have been deposited in quiet water and in a more gentle manner.

These Glacial deposits are spread over large tracts of the British Islands, and are found in all parts except the extreme south of England and Ireland; but they differ so much in different districts, and vary so much even in different parts of the same general district, that few writers have yet attempted anything like a general correlation of them. Our knowledge of them is not yet sufficiently complete for any such attempt to prove satisfactory, and at present, therefore, most districts have each their own local classification and nomenclature.

For descriptive purposes Britain may be divided into the following districts, and some account will be given of the

Glacial deposits which have been described in each of them.

1. East Anglia.
2. Midland Counties.
3. Lincoln and York.
4. Cheshire and Lancashire.
5. Wales.
6. Ireland.
7. North of England and South Scotland.
8. North Scotland.

### 1. *East Anglia.*

In the north-east of Norfolk, where the most complete sections occur, the following divisions have been made, but it should be stated that there is no locality where they can all be seen in vertical succession :—

| | |
|---|---|
| Upper. | Plateau Gravel,<br>Chalky Boulder-clay. |
| Lower. | Sands and Gravels,<br>Contorted Drift,<br>Cromer Till, and<br>Arctic Freshwater Bed. |

The Arctic Freshwater Bed was first described by Mr. C. Reid in 1880,[1] who then distinguished it from the Forest Bed, and placed it at the base of the Pleistocene series because the plants found in it indicate a great change from the climate of the earlier bed. Trees seem to have entirely disappeared, and the plants include the dwarf Arctic birch (*Betula nana*), the Arctic willow (*Salix polaris*), and mosses which now only live within the Arctic circle. It consists of a layer of clay and loam about two feet thick, but is not by any means continuous, having only at present been found at three localities on the coast, viz., Beeston, Mundesley, and Ostend, near Bacton. It rests on the *Leda myalis* bed, and is overlain at the two latter places by the Cromer Till.

The Cromer Till, where thickest near Happisburgh, con-

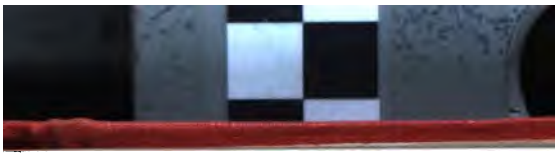
[1] "Geol. Mag.," Dec. 2, vol. vii. p. 548; see also "Geology of Cromer," Mem. Geol. Surv., p. 83.

sists of two beds of tough grey unstratified boulder-clay, with an intermediate band of finely laminated and ripple-marked clay. The Boulder-clays contain fragments of marine shells, with pebbles and boulders of many kinds of rocks, including gneiss, mica-schist, carboniferous limestone, basalt, red and grey granites, pebbles of hard chalk which have been bored by marine annelids, and subsequently striated, and septaria from the Kimeridge clay which have been similarly treated. The laminated beds contain no fossils or foreign fragments of any kind.

The Contorted Drift is usually a yellowish marly and sandy clay full of stones, so that it is really only a variety of Boulder-clay, but it exhibits a rude kind of stratification, and includes knots, patches, and seams of sand and gravel, and the whole has a twisted, contorted, and kneaded appearance. Another remarkable feature of the deposit is the occurrence of large tabular masses of chalk, some of which are 20 to 30 feet thick, and from 100 to 180 yards long. This drift contains boulders similar to those in the Till below and many broken shells, the latter being frequent in the nests and patches of sand, *Tellina balthica*, *Cardium edule*, *Cyprina islandica*, and *Mya arenaria* being the commonest species.

At Beeston Hill (north-west of Cromer) the thickness of the Contorted Drift amounts to 170 feet, and the contortions in this district are very marked, but to the south-east of Cromer they become less, and the deposit finally passes into a tolerably regular bed of stony loam about 30 feet, intercalated between two thick deposits of sand, each from 20 to 40 feet thick, the upper of which contains the same marine shells as are found in the contorted masses near Cromer. The same change into loams, sands, and fine gravels seems to occur as the Contorted Drift is traced to the south-west beneath the Upper Glacial Clay (see fig. 124, p. 504). Moreover, the underlying Cromer Till appears to thin out, so that in the neighbourhood of Norwich the Lower Glacial group consists only of the two following members:—

Stratified sands and gravel, 10 to 20 feet.
Brown stony loam and Boulder-clay, 10 to 30 feet.





Such beds, with occasional intercalations of laminated loam or brick-earth, cover large areas in the east of Norfolk, Suffolk, and Essex, but as the beds are followed to the higher ground in the western parts of these counties, and to the Chalk escarpment in Cambridgeshire, they thin out and are overlapped by the Upper Glacial Clay, which then rests directly on the Chalk.

The Upper Glacial Clay is a stiff bluish-grey Boulder-clay, containing an abundance of ground-up chalk and striated chalk-stones, together with flints and a variety of other rocks; among these the debris of Jurassic rocks is conspicuous, the great clay formations—Lias, Oxford, and Kimeridge clays—have evidently furnished much of the clayey material, for septaria from these clays and pieces of limestone, like the Lincolnshire oolites, are very numerous, and derived fossils such as *Gryphæa incurva*, *Gryphæa dilatata*, *Myacites Listeri*, &c., and *Belemnites abbreviatus*, are not uncommon. In this respect it contrasts with the Boulder-clays of the Lower Glacial group.

This Boulder-clay exhibits a fairly uniform character over a large area, and spreads over a great part of South Norfolk, Suffolk, Essex, Cambridge, Herts, and Middlesex, the most southerly outlier being that on Muswell Hill, north of Highgate; here the clay is of the usual pale colour, and contains occasional fragments of Red Chalk, which must have journeyed a distance of some 100 miles, for the nearest place whence they could have been derived is Hunstanton in Norfolk.

The thickness of this great sheet of Boulder-clay is very variable, sometimes only a few feet can be seen, and in other places borings have gone through 100 or 150 feet of it. Its base-line is very irregular, and it sometimes descends with a rapid slope into valley-like troughs, which are thus completely filled with the clay; the modern valleys often intersect these troughs, but have no definite relation to them; and the excavation of the troughs may reasonably be referred to the action of the same agent that caused the contortions, and formed the Upper Boulder-clay itself, viz., the impact of large masses of ice.

Another fact of some importance in connection with the formation of this clay is the occurrence in it of pebbles

which have been carried up to a level much higher than that of their source; thus phosphate nodules derived from the Cambridge Greensand have been found at a level of 500 feet above the sea, whereas the outcrop of the parent stratum to the north and west is everywhere under 150 feet.

The last and highest Glacial deposit in East Anglia is a coarse flint gravel, which forms isolated plateaux such as Mousehold Heath, near Norwich, and consists mainly of large rolled and battered flints with some pebbles of quartz, quartzite, granite, &c. This gravel attains a thickness of from 20 to 40 feet; it generally rests on the Upper Boulder-clay, and but seldom reposes directly on the Chalk.

### 2. *Midland Counties.*

The Glacial deposits of these counties seldom exhibit so much of a definite succession as those of East Anglia, but in the eastern part of the Midland area the following beds can be distinguished:—

3. Plateau gravels.
2. Upper Boulder-clay.
1. Sands and gravels.

The lower sands and gravels occur chiefly on the lower grounds, and up to levels of 300 or 400 feet; they contain a variety of rock-fragments, but Jurassic detritus generally preponderates; they frequently exhibit contortions and disturbances, and seem sometimes to be abruptly cut off, or replaced by Boulder-clay; this is particularly noticeable in the district between Hitchin and Shefford, and may be due to the forcible impact of ice at the time of maximum glaciation.

The Boulder-clay varies in colour from pale grey to black, being darkest where it rests on the Kimeridge and Oxford clays; lumps of chalk, flint, and oolite limestone are common, and ice-scratched boulders of carboniferous limestone are not rare. This clay is known to occur in the vicinity of Aylesbury and Bicester, but does not extend much farther south.

Coarse gravel of the Plateau type is occasionally found capping the higher elevations of Boulder-clay, and becomes a conspicuous feature in the southern part of the area, especially in Oxfordshire, where all the higher elevations are capped by gravel, consisting principally of rounded pebbles of quartz and quartzite, with some of flint and hornstone. Professor Hull thinks there is no doubt it once formed a continuous covering over this district, and that it has been subsequently removed from those parts which are below a certain level. Along the line of the Thames valley, however, it occurs on minor heights, as low as 300 feet near Wallingford. Westward it reaches into Gloucestershire, and caps the northern summits of the Cotteswold Hills at heights of 600 and 700 feet.

As the Boulder-clay is followed westward it seems to pass into, or to be replaced by clay of rather a different aspect; the chalky form of it extends as far as Rugby and Charnwood Forest, but does not occur far beyond the limits of the Lias, and in Warwickshire its place is taken by a red clay or marl containing rock-fragments derived from formations that lie to the north and north-east, such as occur in the Pennine Hills, Charnwood Forest, and the Hartshill Ridge, with pebbles from the Trias, Jurassic limestones, and flints, but fragments of chalk are rare; its colour is doubtless obtained from the working-up of the Triassic marls and sandstones. About Stafford and Wolverhampton this clay begins to contain erratics from the north-west as well as from the north-east, and this type of clay, often covered by sand and gravel, can be traced up to the watershed of the Trent valley.[1]

The Pleistocene deposits of the Trent basin form the subject of a recent memoir by Mr. R. M. Deeley,[2] who makes a threefold division of the Glacial Drifts in this area, as below :—

| | |
|---|---|
| Newer. | Later Pennine Boulder-clay. |
| | Inter-glacial river-gravels. |

[1] Mackintosh, "On the Drift of the Midland Counties," Quart. Journ. Geol. Soc., vol. xxxvi. p. 178.

[2] "Quart. Journ. Geol. Soc.," August, 1886.

| | |
|---|---|
| Middle. | Chalky sand and gravel.<br>Chalky Boulder-clay, with occasional sands and loams at its base. |
| Older. | Middle Pennine Boulder-clay.<br>Quartzose sands.<br>Early Pennine Boulder-clay. |

The oldest deposits are brownish Boulder-clays, composed almost entirely of materials derived from the Derbyshire Hills; there are often two sheets of such clay separated by beds of clean quartzose sand, which is frequently current-bedded, and is spread over a wide area.

Under the head of Middle Pleistocene he groups—(1) certain stratified sands and loams which underlie the chalky Boulder-clay near Melton Mowbray; (2) the wide-spread chalky clay itself; (3) certain overlying gravels which also contain flints and chalk debris: these last may partly represent the southern Plateau gravels.

Bordering the main river-valleys, and frequently occupying terraces sometimes at least 70 feet above the rivers, are stratified gravels and sands with current bedding pointing down stream; the materials composing these gravels are such as would be derived from the area drained by the river, and the gravels are frequently contorted as if by the grounding of ice. Above these gravels and sweeping down the valley slopes with an average thickness of eight or nine feet is a gravelly Boulder-clay formed chiefly of local materials, with erratics from the Pennine range, some of which are ice-scratched. This latest Boulder-clay is not confined to the valleys, but spreads over much of the lower ground like a mantle, accommodating itself to all the minor features of the district, and is only cut through by the post-glacial courses of the rivers.

### 3. *Lincolnshire and Yorkshire.*

The Glacial Beds in these counties consist chiefly of Boulder-clays, and there are two distinct types or varieties of clay, which appear to be of different ages; but the older is certainly identical with the Upper Glacial Clay of East

Anglia, so that the newer must belong to a later part of the Glacial period than anything which is to be found in the more southern counties, unless it is to be correlated with the Plateau gravels. These two clays occupy separate tracts, and are only contiguous at a few localities.

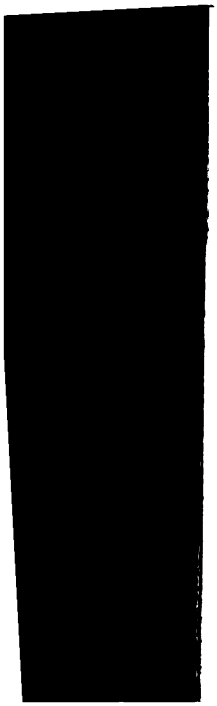
**The Chalky Boulder-Clay.**—The same type of clay described as occurring in the eastern Midlands extends through the counties of Leicester and Rutland into Lincolnshire, passing from the Lias lowlands up to the summit of the Oolitic escarpment. Near this escarpment Jurassic debris decidedly preponderates over Chalk debris, and we again meet with the phenomenon of stones being carried up far above their parent sites. The Boulder-clay of the high ground between Stamford and Grantham is also remarkable for containing huge masses of Lias marlstone and Lincolnshire limestone, which have been carried many miles from the spots whence they were quarried by the ice.[1] These appear to have come from the west and south-west, while carboniferous rocks have come from the north-west, and chalk from the north-east, so that several ice-currents seem to have met in this area.

Local and lenticular beds of sand and gravel occur both beneath and in the Boulder-clay, and patches of Plateau gravel are found on the higher levels with the usual association of quartz, quartzite, and flint-stones.

The same Boulder-clay is also found in the central parts of Lincolnshire, spreading over the Jurassic clays east of Lincoln by Tattershall, Horncastle, Wragby, and Market Rasen; and the increase in the amount of chalky matter in the direction of the Chalk Wolds is particularly noticeable, till near these hills it becomes a stony chalk marl, and has been burnt for lime in some places. There is, however, very little of it on the Wolds themselves, though its occurrence at Kelstern, near Louth, proves that it originally spread over all levels below 400 feet.

Below the escarpment it has been traced northward to Brigg, but has not yet been identified at any place further north in this direction, though it is probable that the lower

[1] See Professor Morris, "Quart. Journ. Geol. Soc.," vol. ix. p. 317, and "Mem. Geol. Survey, Expl. Sh. 70," p. 77.



valleys, and appear to have
heights of 380 feet, but only
level.

They attain a great thickne
100 feet), and rest on a plain
end of which is about 80 feet
level, and which appears to ex
of cliffs along the eastern m
lower part of the clay is nowl
the greater part of the deposit is
clay, containing stones and bou
red Triassic sandstone, coal p
stones and limestones, and volc
Lenticular beds of sand and g
various places, but do not form
horizon. The uppermost part
reddish-brown, with streaks of s
lines of cracking and jointing
probably been caused by the che
water. There are often beds of
this upper clay, and such sectio
there being two Boulder-clays
hence the upper clay has been
the lower the *Purple clay*; but
plete passage from the upper cla
gradually disappearing, withou
sand or gravel

the same set of beds, and show the same red streaky clay, with associated sands overlying brown and purple clays; they are seldom more than 50 feet thick, and they appear to rest on an uneven surface of grey chalky clay which may belong to the older group.[1] At the top of this "Basement Clay" there are twisted layers and patches of sand containing marine shells, and it is supposed that these are portions of a shelly deposit which formed the sea-bottom further eastward at the time when the ice ploughed its way over it, but it is uncertain whether the deposit was contemporaneous or not; among the shells are the Pliocene species, *Astarte mutabilis*, *Tellina obliqua*, and *Nucula Cobboldiæ*, with *Astarte borealis*, *Trichotropis borealis*, and other northern forms. At Dimlington the section is as follows :—

4. Red clay, with blue facings, and patches of gravel at its base.
3. Brown clay, with few chalk stones.
2. Purple clay, with much chalk.
1. Greenish-blue clay, with broken shells, base not visible.

The red and brown Boulder-clays cap the promontory of Flamborough Head, and descend northwards into the hollow of Filey Bay, passing far below the sea-level, and yet forming cliffs 150 feet high. Representatives of the basement clays occur at Speeton and Reighton Gaps, and the complete succession is given by Mr. Lamplugh as follows :[2]—

| | |
|---|---|
| 5. Red clay (6 to 12 feet), with discontinuous layers of gravel at the base (0 to 30 feet thick). | Hessle Beds. |
| 4. Brown clay (20 to 40 feet), with sands, loams, and gravels filling hollows in the underlying bed. | Purple Clays. |
| 3. Purple clay (20 to 40 feet), with patches of clean brown clay at its base. | |
| 2. Blue clay, with shelly patches (as at Bridlington). | Basement Beds. |
| 1. Chalk rubble, with sand containing shells. | |

In the Vale of York there are said to be two Boulder-clays, and the upper contains many fragments of carboniferous rocks from the Pennine Hills, together with granites,

[1] See "Quart. Journ. Geol. Soc.," vol. xli. p. 127.
[2] "Yorkshire Geol. and Polytech. Soc., Proceedings for 1879."

felstones, and porphyries from Norway and the east of Scotland. Writing of the Drifts in the valleys of the Aire and Wharfe, Mr. Mackintosh says,[1] "Lowest of all is the blue clay, which nowhere rises higher than about 600 feet, and which contains many glaciated stones. The yellow or yellowish-brown clay above it rises to much higher levels, contains fewer glaciated stones, and differs from the blue in the kinds of boulders it contains. Above the brown clay at intervals there is a great thickness of sand or gravel, which often forms esker-like mounds."

### 4. *Cheshire and Lancashire.*

Red and brown Boulder-clays with intercalated beds of sand form the mass of the Glacial Beds of these districts; they are called the Low-level Boulder-clays by Mr. Mellard Reade, are sometimes over 100 feet thick, and bear much resemblance to the brown clays of Lincolnshire. On the slopes of the Pennine Hills, however, a different type of Boulder-clay occurs, and the relations of these two kinds of Drift will be best understood from a description of the deposits which are met with in descending the valley of the Ribble from Moughton in Ribblesdale.[2]

Near Moughton the Drift is of a moraine-like character, and consists of coarse gravel and boulder-beds which are composed almost entirely of local materials, viz., Carboniferous Limestone and Millstone Grit, the former predominating. "As we descend, this Drift gets more and more mixed with Carboniferous sandstones and grits from the Pendle Hills and the valley of the tributary Calder." Here, too, it is often underlain by tough blue Boulder-clay, which besides limestone boulders holds some stones that do not occur in the upper valleys, but have been brought from the north and carried up the valley of the Calder against the natural drainage. Near Ribchester the low-level drifts come in, overlapping the more local drift of the Ribble

[1] Op. cit., vol. xxxvi. p. 185.

[2] "On the Drift-Beds of the North-west of England," Quart. Journ. Geol. Soc., vol. xxxix. p. 83.

valley, and consisting of yellow sands with marine shells overlain by a reddish Boulder-clay with broken shells and a variety of stones, many of which can be identified with rocks from the Lake District and the southern uplands of Scotland.

Beneath the Low-level Drift troughs and gullies excavated in the subjacent rock and filled with beds of gravel and clay are frequently found, and there can be little doubt that these indicate the courses of the pre-glacial streams. One of these channels, which may be called the ancient valley of the Mersey, is shown in fig. 131, and Mr. Mellard Reade remarks that if the drift covering could be stripped off the country, a regular system of river-beds would doubtless be exposed, ramifying and uniting into one main channel, discharging northwards through the Irish Sea into the Atlantic.

In the Liverpool district the underlying rocks, where hard enough to receive and retain such marks, are frequently grooved and striated in a north-west and south-east direction, but elsewhere such striæ are exceptional, and the surface of the subjacent rock is more often rough and ragged; sometimes it is covered with a rubble of broken fragments, graduating into red or yellow sand, and sometimes by a clay containing blocks of the local sandstones, but these deposits are always very thin. The ordinary brown Boulder-clay often rests directly on the pre-glacial surface, and Mr. Strahan observes that this is almost invariably the case when the rock-surface is striated.

The Low-level Boulder-clays, like those of the eastern coast, have been divided into an upper and lower clay with a middle sandy division, but Mr. Reade and Mr. Strahan,[1] who are both well acquainted with the Drifts of these counties, agree in thinking that the sands do not form anything like a continuous horizon, but are irregular beds developed at various horizons; consequently no general division into upper and lower clays can be recognized, and single sections often show as many as four sheets of clay, separated by thin layers of sand; the lower clays are generally purple, and the uppermost clay resembles the so-called

[1] "Geology of the Country round Chester, Mem. Geol. Survey," 1882.

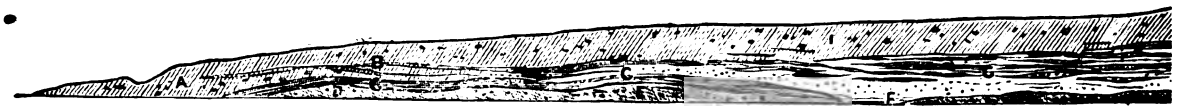


Fig. 130. Section along part of Blackpool Cliffs. Distance about three-quarters of a mile. Borrowed from Mr. Reade's paper in "Quart. Journ. Geol. Soc.," vol. xxxix., p. 109, by permission of the author and the Council.

A A. Red Boulder-clay with fewer stones.
C C. Stratified sands and gravels, intercalated with clay near B.
D E H. Brown Boulder-clay with many stones.

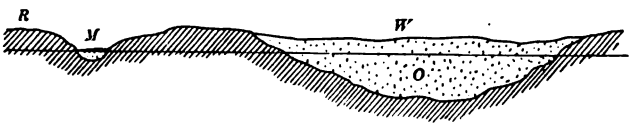



Fig. 131. The buried Valley of the Mersey. Distance about three miles.

M. Modern valley.
O. Ancient valley filled with Drift.
R. Runcorn.
W. Widnes.

Hessle clay of Lincolnshire in being streaked and mottled with grey.

Both Boulder-clays and sands often contain marine mollusca and foraminifera, those in the sands having doubtless been brought by the currents which carried the sand, but those in the Boulder-clay are filled with a fine silt charged with foraminifera, and Mr. Shone thinks they came from silty shores where ground ice formed in the pools between tide-marks, and being frozen into such ice were floated away by the tidal currents and dropped where they are now found. From the Boulder-clays about 60 species of molluscs have been obtained, 18 being decidedly northern forms, while 3 are southern species; from the sands 50 species have been collected, 9 being northern, and the same 3 southern forms occur. The shells have been found at various localities in Cheshire and Lancashire from sea-level up to 600 feet,[1] and at 1,200 feet near Macclesfield.

A good section of the Lancashire Drift is exposed in the cliffs near Blackpool (see fig. 130). Here the lower bed of Boulder-clay is harder and more stony than that forming the upper part of the cliff, but otherwise there is little difference between them; the intercalated sands and gravels are well stratified, and contain many marine shells. Occasionally, as at Lindal in North Lancashire, beds of peat with leaves and trunks of trees occur beneath a great thickness of Boulder-clay.

### 5. *Wales.*

The glaciation of the country, or the manner in which the more exposed rock-surfaces have been grooved and striated by the passage of ice, may first occupy our attention. Sir A. Ramsay has shown that among the mountains the direction of these markings corresponds to the general trend of the larger valleys, and that they must be attributed to the action of glaciers; this is especially noticeable in those valleys which radiate from the Snowdonian mountains to the southward, eastward, and northward. In Anglesey, however, the glacial striæ run from north-east to south-

[1] "Quart. Journ. Geol. Soc.," vol. xxiv. p. 383.

west at right angles to the trend of the great valleys which open on to the Menai Straits, and it is clear, therefore, that the glaciation of that island is not due to the local glaciers; to this point further reference will be made in the sequel. Again, in Flint and Denbigh the striæ run across and not down the valleys, the general direction being from W.S.W. to E.N.E., and all the evidence is against their having been produced by valley-glaciers or by land-ice in any form.[1]

Coming now to the Glacial deposits, it would appear from the observations of Mr. Mellard Reade and Mr. Strahan that the same distinction between Mountain and Low-level Drifts holds in North Wales as in Lancashire; the former consisting of Boulder-gravels and clays, the contents of which have been chiefly derived from the rocks of the valleys in which they lie, while in Flint and Denbigh there are deposits of sand and clay which strongly resemble the Low-level Drift of Lancashire. Farther, the Drift with local boulders appears to pass below that in which foreign erratics abound; thus Mr. Reade describes the following succession as visible in the cliffs of Colwyn Bay:—

4. Brown Boulder-clay, with broken shells and some northern erratics, and including a band of laminated clay.
3. Obliquely stratified sands, resting on an eroded surface.
2. Cream-coloured till in discontinuous patches.
1. Hard bluish-grey till packed full of stones derived from the Carboniferous and Silurian rocks of Wales.

Of the upper sands and clays Mr. Reade says, "they are not what the immediate coast or mountains could yield, but are composed principally of Triassic debris mixed with travelled and striated rocks."[2]

Near Llandulas, at a height of about 500 feet above the sea, there is an extensive deposit of stratified sand and gravel in which marine shells occur, and reddish Boulder-clay rises to above 400 feet in the Vale of Clwyd.

Similar beds occur on the coast of Anglesey, near Beaumaris, where reddish clay containing a variety of rock-

[1] See A. Strahan, "On the Glaciation of Cheshire and the Welsh Border," Quart. Journ. Geol. Soc., vol. xlii. p. 369.
[2] "Quart. Journ. Geol. Soc.," vol. xli. p. 106.

fragments overlies brownish-grey clay with large blocks of carboniferous limestone, and at Lleiniog the upper clay rests on sands and gravels with pebbles from many sources. In the west of Carnarvonshire there are vast accumulations of gravel and boulder-beds which sweep up the slopes of the hills to heights of 800 and 1,000 feet; and on the summit of Moel Tryfaen, a hill overlooking Carnarvon Bay, with a height of 1,350 feet, there is an extensive deposit of stratified sand and gravel containing marine shells, no fewer than fifty-five species having been obtained; it is irregularly overlain by Boulder-clay, and both deposits contain erratics from Cumberland and Scotland, as well as chalk flints which came probably from Ireland. These flints, as Mr. Mackintosh observes, have travelled to a higher level than their source, for the highest parts of the Irish Chalk are between 900 and 1,000 feet.[1]

Similar shell-bearing gravels have been found by Mr. Mackintosh at heights of 1,100 to 1,230 feet on the east side of the hills near Minera in Denbighshire; here also Eskdale granite, Cumberland felstones, and chalk flints are mixed with the debris of local rocks, and all are well rolled and rounded as if they had formed part of a sea-beach. This pebbly condition appears to be characteristic of the gravels between levels of 1,000 and 1,400 feet, while between heights of 500 and 1,000 feet the stones in the Drift are mostly angular. Above 1,400 feet there are again angular gravels, and boulders of Arenig felstone occur in the Minera district up to a height of 1,900 feet, proving a submergence of at least 2,000 feet, and the stranding of ice-floes from the Arenig Hills (fifty miles to the west).

Much less is known about the Glacial deposits of South Wales; those of Brecon and Glamorgan have been examined by Mr. J. W. E. David,[2] who describes the whole area as having a moutonnée aspect, and the surfaces of the harder rocks as being frequently striated, the direction of the striæ varying between south-east and south-west, but always pointing southward. In Pembrokeshire, according to information supplied by Dr. Hicks, the usual direction is from north-west to south-east.

[1] "Quart. Journ. Geol. Soc.," vol. xxxvii. p. 366.
[2] *Ibid.*, vol. xxxix. p. 39.

Boulder-clay occurs in patches, generally filling depressions, over the whole area from 20 to 1,200 feet above the sea. Erratic blocks are frequent between the same limits; erratics of Old Red Sandstone and Millstone Grit occur on ground which rises to over 1,000 feet between the Aberdare and Neath valleys in Brecon, the boulders of the former having probably travelled from the Beacon Hills, and those of the latter from high ridges of Millstone Grit which lie to the north-west.

In West Pembrokeshire there is no great thickness of Drift except in certain valleys and in places along the coast, but stratified gravels and transported boulders are of frequent occurrence between the sea-level and heights of 500 feet. These gravels contain boulders of rocks which are unknown in South Wales.

### 6. *Ireland.*

The glaciation of Ireland presents some remarkable features: the prevalence of ice-marks running from N.N.W. to S.S.E., and the frequent occurrence of roches moutonnées sloping to the N.N.W., prove that there was a time when the general movement of the ice was from that direction. This general trend is particularly noticeable throughout the southern, central, and eastern parts of the country; in Connaught and Ulster, however, the ice-marks vary greatly in direction, pointing south-west about Galway Bay, W.N.W. round Clew Bay, due north round Killala Bay, north-west down the valley of Lough Erne, and north-east in Tyrone. It is supposed by Rev. Maxwell Close and by Professor Hull that these facts indicate the existence of a great central snowfield, the axis of which ran through the north of Ireland from Lough Corrib on the west to Lough Neagh on the east; but as the average elevation of this tract is not more than 400 or 500 feet above the sea, and the ice-marks occur on mountains up to heights of 1,500 and even 2,000 feet in Mayo and Connemara, it is difficult to accept this hypothesis. It is more likely that the striæ have not all been produced at the same time or by the same agent; some were made by the early glaciers, some by sea-

ice during a time of submergence, and some by the later glaciers which occupied the mountains on their re-elevation, and it is obviously difficult to distinguish between the striæ made at these different stages of the Glacial episode. It is indeed admitted that the mountainous districts had their later glaciation, and that the marks made by the later glaciers often cross those made by the earlier ice-sheet. As Professor Jukes has well observed, "it must be recollected that during the submergence of the land, and during its subsequent elevation, every conceivable gradation of relative altitude must have existed at one time or another between the present levels of the land and its greatest depression."[1] Thus, for instance, the Ox mountains in Sligo may have been scored by sea-ice at one time, and have nourished glaciers at another, the latter carrying detritus to the sea-level, both on their northern and southern flanks.

On the Glacial Deposits of Ireland much has been written, but no one has yet given a satisfactory or comprehensive account of them. Enough is known, however, to make it obvious that they were accumulated under the same conditions as those of England; those of northern and eastern Ireland indeed greatly resemble the Drifts of western England, but those of the central and western districts constitute rather a different type, though probably the one set pass into the other.

The central plain of Ireland "is largely covered by a widely spread mass of Drift, consisting of dark sandy clay with pebbles and blocks and occasional beds of sand and gravel, which are sometimes very regularly stratified. The great majority of the pebbles are rounded fragments of Carboniferous Limestone, whence the deposit usually goes by the name of the Limestone Gravel. This deposit rests not only on the limestone, but sweeps up on to the flanks of all the hills which rise from the central plain. In such case the limestone gravel (often) becomes largely mingled with the detritus of the rocks of which the hills are made, . . . but gravel almost entirely composed of limestone pebbles is found up to heights of 1,200 feet on the granite mountains

[1] "Manual of Geology," second edition, 1862, p. 681.

south of Dublin. It spreads across the lower part of this granite range, and runs down by Bray into the county Wicklow, where it is covered by beds of sand and marl that spread through Wicklow and Wexford over all the low grounds between the mountains and the sea-coast." [1]

Where this Limestone Drift reaches to mountain districts, it seems to have completely filled up the preglacial valleys, and the aspect now presented by such valleys is thus described by Professor Jukes:—"The steeper hills, as they descend into the valleys, are met by gently sloping plateaus of Drift, forming inclined planes from the heads of the valleys towards their mouths; these inclined planes seeming once to have stretched continuously across the valleys, but being now deeply trenched by the ravines at the bottom of which the present brooks run. These have excavated channels for themselves either through the Drift, or between it and the solid rock, leaving the gently sloping surface of the Drift often most distinctly marked along the flanks of the more abruptly rising hills on each side of the valleys" (op. cit., p. 676). He mentions Glenismaule, near Dublin, and the valleys of the Slieve Bloom mountains (Queens Co.), as localities where these features are characteristically exhibited.

In some cases this Limestone Drift overlies a deposit composed entirely of local rocks, as in Glenbarrow, on the northern flank of the Slieve Bloom. Here at a height of 800 feet the river runs below a cliff 120 feet high, which is entirely formed of stratified Drift, and exhibits the following succession:—

| | Feet. |
|---|---|
| Coarse Drift, with limestone boulders . . . . . | 50 |
| Fine laminated sand . . . . . | 20 |
| Rubbly sand, with angular blocks of Old Red Sandstone, the same rock lying below . . . . . | 50 |

The Limestone Drift runs up this glen to a height of 1,260 feet, and Mr. O'Kelly found pieces of limestone and black chert even on the hill-tops above the level of any

[1] Quoted from Jukes, "Manual of Geology," 1862, p. 675. The higher beds here mentioned by Jukes seem comparable to the newer Low-level Drift of Wales and Lancashire.

other drift. This Drift, however, does not seem to extend south of the high land which crosses Ireland from Waterford to the coast of Kerry, the deposits on the southern slopes of this region being mainly composed of local rocks (Jukes, op. cit., p. 679).

Marine shells are occasionally found in these gravels, and are usually of the same species that occur in England. They occur chiefly below 600 feet, but on Three Rock Mountain in Wexford they occur at a height of 1,300 feet, and include some more southern forms, as *Artemis lincta*, *Venus striatula*, and *Venus casina*.

On the west coast there are immense accumulations of Drift, which are well exposed in Clew and Galway Bays, and some of which are probably sloping piles of Drift similar to those described by Jukes, only intersected by marine erosion. Mr. Mellard Reade thus describes the material forming Blake Hill, near Galway:—"The whole hill is composed of a mass of calcareous detritus extremely finely comminuted. It contains many boulders and large stones, the majority being limestone, and the next in quantity granite. The sea has eaten into the originally rounded hill and made very fine cliff-sections; and such is the compactness with which this calcareous cement has set that the cliffs are vertical, and indeed in some places overhang."[1]

On the north-east coast there are deposits similar in all respects to the Low-level Drifts of Lancashire, consisting of red and brown Boulder-clays, with frequent intercalations of sand containing marine shells. Cliff-sections of such beds are frequent along the coasts of Antrim and Down, and their marine origin is proved not only by the shells in the sands, but by the presence of *Leda pernula* and *Leda minuta* with attached valves in Boulder-clay at Woodburn Glen, near Belfast (M. Reade, op. cit.).

Southwards these reddish clays appear to overlie the Limestone Drift, as seen in the cliff-sections at Killiney and Ballybrack, south of Dublin, and they attain a great thickness near Carlow, where the following succession was

[1] "Notes on the Scenery and Geology of Ireland," "Proc. Liverpool Geol. Soc., 1878-79."

found in sinking a colliery shaft (Hull, "Physical Geology of Ireland," p. 91):—

| | | Feet. |
|---|---|---|
| Newer. | Stiff red clay, with stones | 84 |
| | Laminated clay | 5 |
| Older. | Sand, with pebbles of limestone | 25 |
| | Strong clay, with stones | 8 |
| | | 122 |

As regards the dispersal of boulders, Professor Jukes mentions the following facts:—"The Leinster granite sends off boulders in all directions except the north, but chiefly toward the south-east. . . . The granite, which occupies a large area on the north side of Galway Bay, is easily recognizable, inasmuch as it is . . . a porphyritic syenitic granite. Blocks of it may be found scattered over all the country to the south of the bay, through Clare and Limerick, as far south as Mallow in the county Cork, a distance of about 100 miles in a straight line. They occur also in the country about Nenagh, and on both flanks of the Slieve Bloom hills up to heights of 1,000 feet" (op. cit., p. 678). "Chalk flints and pieces of hard Antrim chalk are found in Drift in the counties of Dublin and Wicklow, up to heights of one or two hundred feet, and along the whole eastern and southern coast of Ireland, at least as far as Ballycotton Bay, on the coast of Cork" (p. 675). On Three Rock Mountain in Wexford they occur up to 1,200 feet.

No notice of Irish Drifts would be complete without a reference to the long winding banks or ridges of gravel which are known as Eskers. These ridges often rest on the surface of the other Glacial deposits, and from these the materials composing them have been chiefly derived. They often extend in sinuous lines for many miles, but are confined to the plains and low grounds, not extending above the 400 feet contour. They may therefore be regarded as among the latest of the Pleistocene deposits, but the occurrence of large boulders on these banks shows that floating ice was still present.

Morainic mounds occur in some of the valleys of the more mountainous regions, and testify to the existence of small valley glaciers during the last stage of the Glacial period.

### 7. *North England and Southern Scotland.*[1]

The glaciation of the North of England is traceable chiefly to two main centres,—the mountain cluster of the English Lake District, and the massive Fells of Galloway in Scotland. Little record is left of the earlier phases of the Glacial period. But to the sporadic radiation of boulders from these centres we doubtless owe much of the strange intercrossing and intermingling that marks their after-distribution. In many cases they may have found their way into their present position, not from the parent rock direct, but from various points within the circles of early dispersal.

The striation of the Lake District is attributed to glaciers which moved out through its radiating dales in almost every direction, the chief axis of movement being that of the principal watershed which runs through its centre approximately east and west, while the lower valleys and their parting ridges, according to Mr. Clifton Ward,[2] became gradually buried under a confluent ice-sheet. In Galloway heavy glaciers moved out from the central granitic masses; and the glaciers of the two districts came together, there is no doubt, upon the plains of the Solway basin.

The further distribution of striæ and boulders is curious in the extreme. From Galloway it is remarkable that they pass very little to the northwards. On the west they bend along the coast as if to join the south-west stream of striæ making down from the Highlands through the now submerged valleys of Argyleshire upon the broader vale of St. Patrick's Channel. On the south they point freely south-

[1] This section is a contribution from the pen of Mr. Hugh Miller, F.G.S., whose personal acquaintance with the district makes it more valuable than any description the author could have compiled from published sources. It should be mentioned, however, that Mr. Miller attributes more to the action of land-ice, and less to that of sea-ice, than the author is inclined to allow. This difference of opinion will be referred to on a future page.

[2] J. Clifton Ward, "The Glaciation of the Northern Part of the Lake District," "Quart. Journ. Geol. Soc.," vol. xxix. (1873); "The Glaciation of the Southern Part of the Lake District," "Quart. Journ. Geol. Soc.," vol. xxxi. (1875).

ward, and their direction is continued over the Isle of Man and Anglesea. They have the same southward tendency in the Lake District. They pass no great distance north or north-west—not far beyond Carlisle—but stream off freely to the south. And from the eastward continuation of the principal watershed (the neck of fells between the Lake District and the Pennine range) they are shed southward over North Lancashire, not only down the valley of the Lune and along the low seaboard, but, as shown by Mr. Tiddeman,[1] over by Ingleborough Hill, as if regardless of gradients, into Ribblesdale, crossing many considerable valleys, and overriding hills up to 1,500 feet.

In easterly directions the evidence is still more curious. In the south-eastern part of Galloway, as was shown by Mr. Horne, they point across the Solway—Crifell, 1,800 feet high, standing in their way somewhat like a graduated mark in a tide-way. In Dumfries there are some striæ and boulders that mark a line of movement across the valleys of the Annan and the Esk, abutting against the west end of the Cheviot Hills, and entering the basin of the Tweed. But the main stream of striation, joined towards the south by striæ and boulders from the Lake District, passes to the east coast of England. The greater part of it crosses over the watershed between the Cheviots and the northern shoulder of Cross Fell (both of which hill-groups had small ice-caps of their own), at heights of from 600 to 1,700 feet; it skirts the Cheviot range, covering their flanks up to 1,600 feet, but apparently at lessening heights as we trace it on; it fans out perceptibly upon Northumberland, and spreads over the plains of East Durham and the Vale of York. The Cleveland Hills bear neither striæ nor foreign drift, as if "the glacial matter was unable to surmount a barrier of even 700 feet."[2] To the south of Cross Fell a smaller stream of boulders and striæ from Galloway and the Lake District concentrates upon the Stainmore Pass, and carries the boulders of Shap Fell to

[1] Tiddeman, "On the Evidence for the Ice-sheet in N. Lancashire," &c., "Quart. Journ. Geol. Soc.," vol. xxviii. p. 471 (1872).

[2] "Handbook to Middlesborough and District," "Geology," by W. Y. Veitch and Geo. Barrow, F.G.S.

the east coast through Teesdale.[1] Towards the seaboard of Northumberland and Durham the path of this eastward glaciation is crossed by a stream of striæ passing south, as along the western coasts.

Turning now to the Glacial deposits, we remark that it is not only in the striation of the rocks that these movements are recorded, but also in the structure of till or lower boulder-clay, which enwraps the country with an irregular sheet of miscellaneous off-scoured matter extending from the flanks and hollows of the hills (as high sometimes as 1,800 feet) down to the sea. The chief boulders of the till are striated *in situ* in the same general direction and with the same firmness and evenness as the striæ on the rocks. The till of Northumberland has been likened to one vast irregular "striated pavement." The smaller boulders have their axes very frequently drawn into the line of glaciation (as in fluxion-structure), as if by a heavy dragging movement. At the surface it is often shaped into sow-backs or *drumlins* stretched in the same direction. All these features of the till are remarkably developed on the watershed of England among the Bewcastle Wastes, north of Gilsland in Cumberland.[2] The composition of the till, again, shows that the outcrops of rock lying in the path of movement—all the way from the red rocks of Cumberland, for instance, to the coaly shales of Newcastle—contributed one after the other their quota of materials, the boulders being gradually reduced in size and rubbed down into clay, &c., as if by sustained friction, as they were carried on. The texture and colour of the till thus constantly varies;—it is bright Indian red on the red rocks; leaden-coloured and clayey on the carbonaceous rocks; sandy and raw where the pale carboniferous sandstones predominate; brown and dry on the Cheviot porphyry; and when it rests on composite formations such as the Carboniferous Limestone series, it never remains for half an acre the same. Among the slopes of the higher hills it is thin, loose, local, angular, and almost morainic-looking;

[1] J. G. Goodchild, F.G.S., "The Glacial Phenomena of the Eden Valley," &c., "Quart. Journ. Geol. Soc.," vol. xxxi. p. 55 (1875).

[2] "On Boulder-Glaciation," H. Miller, "Proc. Royal Phys. Soc., Edinb.," vol. viii. p. 156.

in the valleys and low grounds it becomes dense and well-kneaded up, and contains a larger assortment of boulders; in the lower grounds it is often gravelly and much intercalated with seams of sand and gravel and laminated clay without stones; but it is the same deposit throughout. Irregular beds of gravel are not unknown even at the very bottom, as in some parts of East Cumberland. At several places near Berwick it contains well-glaciated fragments of shells of Northern type.[1]

The overlying deposits are not so well understood. In the Isle of Man Mr. Horne describes an important section near Ramsey,[2] where a lower boulder-clay or till is overlain by finely-stratified sands and gravels, "evidently a marine deposit," above which is a stony clay (6 to 8 feet thick) resembling the maritime boulder-clay of Scotland. In West Cumberland Mr. Kendall[3] describes sands and stony clays which he believes to be a continuation of the uppermost sands and Boulder-clays of Lancashire. On the east coast there is undoubtedly an upper boulder-clay limited to the maritime districts, and to elevations under 350 feet, and lying in the track of the north and south coast-glaciation. It is divided from the till either by aqueous sand and gravel, or an eroded junction line. It seems to be the same deposit, very uniform in character, that is found all along the sea-board from Aberdeenshire southward, differing

[1] "The Great Ice Age," by Professor James Geikie, second edition, p. 167; and W. Gunn, "Berwicksh. Naturalists' Field Club Trans., 1885."

The preceding facts, in the opinion of the writer, are part of a remarkable body of evidence pointing to the existence of a great ice-sheet moving from the Highlands of Scotland southwards through the Irish Sea, and re-inforced by ice masses from Ireland, Galloway, and the Lake District. The same evidence shows that the excessive constriction was partly relieved as if in the direction of least resistance over the comparatively low bar of fells forming the watershed of England. The "striated pavements," the fluxion structure in the till, the heavy close drag of the striating agent across every outcrop in its path, and the evident thinning out of the sheet as it spread over eastern Northumberland and round the Cleveland Hills, do not seem to consort with any other explanation.—H. M.

[2] J. Horne, F.G.S., "A Sketch of the Geology of the Isle of Man," "Trans. Geol. Soc. Edinb.," vol. ii. part iii. (1874).

[3] J. D. Kendall, C.E., "The Glacial Deposits of West Cumberland," "Trans. Cumb. Scientific Assoc.," part vii.

from the till by its uniformly reddish colour and the fewness and smallness of its stones. On the coast of Northumberland, as observed by Mr. Howse, it contains a few flints, perhaps derived from deposits at the sea-bottom.

The "great submergence" has left singularly few traces over the greater part of England north of Lancashire and York. But Mr. Clifton Ward[1] describes certain transported boulders left lying at great heights among the mountains of the Lake District, which he is inclined to consider as a *proof* of submergence to the height of at least 1,300 feet.

The latest deposits of the Glacial period in the North of England are, 1st, the ridges and mounds of tumultuously stratified gravel and sand known as kames (or eskers), and 2nd, moraine-mounds of angular debris. The moraines, which abound in the upper valleys of the Lake District, are the debris-heaps of the last shrunken glaciers. In Northumberland they are few and small. The gravel mounds are of more equivocal origin. In some cases, near Otterburn in Northumberland, they merge into moraines; one part of a single mound may be moraine and the other part kame. These kames are of true morainic origin. The winding kame-ridges, which, like the drumlins of the Drift, extend in the direction of ice-movement (though only a single chain of them crosses the watershed of England, *i.e.*, through the shallow watershed-valley at Gilsland), are often supposed to be marine, but this is by no means certain, or even probable.

Mr. Miller's account of the Glacial deposits of the Border country will apply equally to those of the southern uplands of Scotland, but the following are a few facts culled from Dr. A. Geikie's "Memoir on the Glacial Drift of Scotland."[2]

The ice which covered the central uplands in Peebles and Lanark seems to have had a movement northwards as well as eastwards and southwards, for the Boulder-clay on the

[1] "Memoirs of the Geol. Survey of England and Wales," "The Geology of the Northern Part of the English Lake District, 1876," p. 98.

[2] "Trans. Geol. Soc. Glasgow," vol. i. 1863.

north side of the Medwin valley contains many rock-fragments brought from the country to the south, but none from rocks lying to the west or north.

Stratified sands and gravels occur both in the valleys and on the hill-sides, and even on watersheds up to a height of at least 1,000 feet, *e.g.*, on the watershed between the Medwin and the Tarth (700 feet), and between the sources of the Yarrow and the Moffat Water (up to 1,000 feet).

Eskers, or *Kames*, as they are called in Scotland, are not uncommon, generally occurring on low flat ground or along wide valleys, but sometimes they cross the mouths of tributary valleys and are intersected by the streams. When cut open they often exhibit a curious arrangement of the component strata, which are inclined outwards and downwards from the central axis of the ridge.

Moraines are frequent in the higher parts of the larger valleys, such as those of the Tweed, Annan, Moffat, Megget, and Talla waters; Loch Skene, for instance, is a tarn held up and half enclosed by morainic mounds (Geikie, op. cit., p. 164).

### 8. *Central and Northern Scotland.*

The following account of the Glacial phenomena of these districts is taken principally from Dr. A. Geikie's excellent "Memoir on the Phenomena of the Glacial Drift of Scotland," with some additions from more recent sources.

**Glaciation.**—The rocky regions of Scotland nearly everywhere exhibit the peculiar rounded and moulded outline which is characteristic of ice-action, and nowhere are these swelling contours more distinct than on the slopes which rise from the central lowlands. Wherever, too, the smoothed surfaces of the rocks have been protected from atmospheric influences by a covering of turf or clay they exhibit the striations and groovings left by the passage of ice-borne stones; such striated surfaces occur not only on the summits and flanks of lofty mountains, but also along the shores of the lochs and firths, and are often seen to pass beneath the level of the sea.

The direction taken by the striæ at any locality is, of

course, a guide to the direction taken by the ice which made the marks, and observation has shown that, as a general rule, the striæ run parallel to the main valleys of the country, and that they radiate outwards from the great central mountain ranges. Thus there is ample proof that the Grampians formed one axis of dispersal, for down the valleys which open on to the Clyde the striæ run south or south-east, down Loch Fyne they run south-west, while at the north end of Loch Awe and thence over the country to Loch Linnhe the direction is uniformly from east to west; down the valley of the Spey they run north-east, in Aberdeen nearly due east, while in Perth, Fife, and Forfar the directions are south-east and E.S.E. The highlands of Sutherland formed another centre whence the ice radiated in every direction.

There are, however, exceptions to the coincidence between the run of the striæ and that of the main valleys; thus the district known as Knapdale in Argyleshire, which rises to 700 or 800 feet above the sea, is glaciated obliquely from north-east to south-west, as if the ice had filled up the valley of Loch Fyne, and had flowed over the ridge to the Sound of Jura. There seems also to have been a time when the ice from the Perthshire highlands went across the Ochil Hills, some of which reach a height of 2,300 feet, and these are important facts to remember when the mode of glaciation is considered.

**Glacial Deposits.**—The following is a general classification of these deposits, but it is seldom that all the members are found in one locality:—

5. Moraines of local glaciers.
4. Shell-bearing clays near the coast.
3. Upper Boulder-clays with broken shells.
2. Stratified sands and gravels.
1. Lower Boulder-clay or Till.

It is probable, however, that some of the stratified deposits are coeval with the Boulder-clays, and that the moraines were more or less contemporaneous with the later shell-bearing clays.

The Till is described as a very stiff clay full of stones and boulders, or rather as a mixture of gritty clay, gravel,

and boulders, the whole being so hard and compact that it often weathers like a conglomerate. Boulder-clay of this kind occurs up to heights of 1,600 feet, and is sometimes over 100 feet thick, being always thickest on the low grounds and thinning away on the highland slopes. The stones and boulders are principally derived from local rocks, and in the lowland clays there are not many stones which have travelled more than a few miles from their parent site; most of the fragments are smoothed and striated, and many are scratched all over, often exhibiting five or six definitely striated surfaces. The local character of the clay is also shown by its variations in colour. Hugh Miller, sen., long ago remarked that red sandstones were covered by red boulder-clay, the grey flags of Caithness by a lead-coloured clay, and the coal-measures of the Lothians by a bluish-black clay; subsequent observations have shown that the clays of these colours do not exactly coincide with the limits of the formations from which they derive their tint, but slightly overlap them in an outward direction: thus in the basin of the Forth the red clay passes eastward on to the coal-measures for a certain distance, before it is replaced by the clay which derives its tint from those measures.

Thus, though the materials of the Boulder-clay afford evidence of a certain amount of transport, still its local character is so strongly marked, that "whatever may have been its mode of production, it cannot have been carried from a distance, but must have been formed on the whole in the districts in which it is found."[1]

Stratified beds (sand, silt, and laminated clay) are occasionally found in the hard till, and in some cases they have yielded marine shells of Arctic species, and in other places they include peaty beds with bones of the mammoth and reindeer.

In many places the hard till above described is covered by deposits of a more varied character, and consisting of stratified sand, gravel, and clay—mounds and terraces of well-rolled gravel occur in many Highland valleys far above the present streams; similar deposits occur as patches

[1] Geikie, op. cit., p. 43.

on the hill-sides, and they occupy large areas in the central lowlands between the firths of Forth and Clyde. Associated with these beds or stranded on bare hill-sides are numerous large erratics or transported boulders, which have usually come from points to the north or north-west of the positions they now occupy, and some have travelled distances of 50 or 60 miles; it is to be noted that such boulders are rarely or never found in the older Boulder-clay, though they often lie on it. Dr. Geikie regards the stratified Drift as marine, and believes the erratics to have been carried by sea-ice.

Along the coast of Aberdeen, from Stonehaven to Peterhead, a very different kind of Boulder-clay is found; this is a reddish-brown clay which appears to resemble the brown clays of Yorkshire and Lincolnshire; it contains broken marine shells, and often includes seams of fine sand or laminated silt; moreover, its materials appear to have been derived from the southward, from the Old Red Sandstone districts in Kincardine and Forfar, a conclusion which is confirmed by the occurrence of striæ on the rocks below, pointing from S.S.W. to N.N.E. Near Collieston and Slains this clay rests on a set of stratified sands and gravels which contain numerous broken marine shells, but these seem to have been derived from the destruction of Pliocene beds, comparable to the English Crags. The cliff-section near Collieston is given below:—

| | Feet. |
|---|---|
| 3. Red clay . . . . . | 16 |
| 2. Brownish-grey sand and silt . . . . . | 55 |
| 1. Coarse grey rubbish resting on gneiss . . . . | 8 |

The red clay varies from 10 to 30 feet in thickness and reaches inland up to heights of 300 feet, and pebbly gravels with broken shells range up to 470 feet.

In the basin of the Clyde there are certain deposits which were evidently formed during the last stage of the Glacial epoch; the usual succession of these beds is as follows:—

3. Sandy clay or sandy gravel.
2. Fine grey clay, with many perfect shells.
1. Laminated reddish clay, without shells.
Hard tough boulder-clay, with striated stones.

There is always a layer of laminated, stoneless, and shell-less clay between the till and the shell-bearing clay (No. 2), but its thickness varies from 1 to 18 feet. The clay above is a consolidated mud through which many stones, both rounded and angular, are scattered, but its consistency is not that of boulder-clay, and the stones are not glaciated; the shells which occur in it are generally perfect, and are of northern and arctic species. These clays fringe the Firth of Clyde from Glasgow westward, and pass up the Kyles of Bute to Loch Fyne; they are also found on the shore of Loch Lomond, but do not anywhere extend beyond 50 feet above the sea.

Inland, the last phase of the Glacial epoch is marked by the occurrence of terminal moraines in many of the Highland valleys; sometimes several such moraines occur one above another, and huge blocks of rock are often perched on the top of them as well as on the neighbouring slopes, while the course of the glen above the highest moraine is swept clear of all such detritus.

Kames are found in some districts, and Mr. Hugh Miller informs me that in Easter Ross the ends of all the kames are markedly levelled out into horizontally stratified sheets of gravel all along the line of the 100-foot beach of that district.

### b. Post-Glacial Deposits.

The deposits which are usually termed Post-glacial must not be regarded as representing a totally distinct and later stage of Pleistocene time; for the recession of the glacial conditions to the Arctic regions was a gradual process, and glaciers lingered in the North of England and in Scotland long after the rest of England had become a habitable country. Consequently deposits which are post-glacial in relation to the Boulder-clays of East Anglia may be contemporaneous with the later Glacial clays of Scotland; and until the history of Pleistocene times is more completely known, the extent to which Post-glacial deposits may dovetail into those usually called Glacial cannot be precisely indicated.

It would be impossible within the limits of this volume

to give anything like a comprehensive account of the river-gravels, cave-earths, and alluvial beds which make up the Post-glacial deposits of Britain. Only a few examples of each will therefore be described in the following pages. It is doubtful whether the fluviatile deposits of different valleys will ever be correlated satisfactorily with one another; at present we can only say that some are older and some are newer, that the former contain rude implements fashioned by man out of flint and stone (*Palæolithic*), while the latter contain implements of a more finished type (*Neolithic*).

**River-Gravels.**—The manner in which beds of sand and gravel have been formed and left in disconnected tracts or terraces at various levels above the present streams has been explained in a former volume ("Physical Geology," p. 162). The account there given applies to the upper and central parts of any river-valley, but in the lower part of a valley where the river is tidal the differences between the levels of the terraces become less and less, and near the river's mouth the relation of the older to the newer gravels will depend on the earth-movements which have been in progress during their deposition. If the whole drainage-basin has been elevated the older gravels will be everywhere at higher levels, but if submergence has taken place the older beds may pass beneath the modern estuary, or may not be far above the level of the modern alluvium. In such cases, however, they will still be considerably above the *base* of the alluvium, *i.e.*, the channel occupied by the river before submergence set in, and this therefore is the level from which their height should be estimated.

The deposits in the valley of the Thames may be taken as an example of such accumulations. In the higher parts of the valley tracts of gravel are found at various heights, now on one side of the river, now on the other; three stages or terraces can often be distinguished, the highest being about 30 feet above the level of the river. From this highest terrace few bones have been obtained, but at the lower levels land and river shells, with remains of *Elephas primigenius, Elephas antiquus, Rhinoceros tichorhinus, Bison priscus, Cervus tarandus, Equus caballus,*

*Canis lupus*, and *Ursus arctos* are frequently found. Between Windsor and London the outspreads of gravel become wider and more continuous, but the surface of the older parts still rises to 30 and even 45 feet above the river, and the shells are still of fluviatile species. Hence we may conclude that when these gravels were deposited the Thames had a much longer course than it has at present, and that this part of the valley was then far inland, otherwise the beds would be at a lower level, and the shells would be estuarine. In these gravels, at Acton and Stoke Newington, many flint implements of Palæolithic type have been found.

Below London, at Ilford, Grays, Crayford, and Erith, there are a series of gravels, sands, and loams which rise to 25 or 30 feet above the river, but are nearly 60 feet above the base of the alluvium at Erith. These beds have yielded the mammalian remains mentioned on p. 515, and it is only at these places that *Rhinoceros leptorhinus* and *Rh. tichorhinus* have been found together. The presence of *Rhinoceros megarhinus* (a Pliocene form), and the absence of the Reindeer (*Cervus tarandus*), are regarded as indications of the antiquity of the deposits. Between fifty and sixty species of land and freshwater shells have been found, several of which no longer live in Britain, *e. g.*, *Cyrena fluminalis*, *Unio littoralis*, *Hydrobia marginata*, *Paludina contecta*, *Valvata piscinalis* var. *antiqua*. A worked flake proving the presence of Man has also been found in the lower brick-earth.

At Crayford and Ilford the total thickness of the deposits is from 20 to 30 feet.

Still farther east, at Clacton, on the coast of Essex, there is a deposit of loam with freshwater shells, which extends below the level of the beach, and is overlain in the cliff by red loam and brown shaly clay with estuarine shells. Many of the same mammalia have been found here, and Professor Dawkins regards them as a continuation of the Thames valley deposits, the freshwater loam having probably been deposited when the land stood at a higher level.

The district now drained by the river Cam contains an interesting series of river deposits, which bear testimony to the successive changes that have taken place in the drainage

system of this area. The oldest line of gravels has no connection with the modern river-valley, but crosses it nearly at right angles near Cambridge. Patches of gravel in the hill-valleys near Balsham testify to the action of streams where none now exist, and these seem to have united to form a river which ran by Wilbraham, Quy, Cambridge, Girton, Oakington, Long Stanton, and Willingham.[1] The deposits it has left now form long gravel-capped ridges, the base of the gravels where intersected by the Cam being about 40, and their surface sometimes 60 feet above the modern alluvium. These fluviatile gravels appear to terminate abruptly above the fens of the Bedford Level, but were probably originally continuous with the gravels at Chatteris, Doddington, and March, which form similar ridges rising above the general level of the fens which surround them, and evidently mark the estuarine channel of a river which traversed the country when it stood at a somewhat lower level, and before the Fen-land existed. The shells found at March are chiefly marine, but include *Cyrena fluminalis*.

Of deposits which bear a definite relation to the modern river Cam, remains of three terraces can be recognized, the highest of which is at Barnwell about 25 feet above the alluvium, and has yielded a number of mammalian bones and teeth, with a still larger number of shells, among which *Cyrena fluminalis*, *Unio littoralis*, and *Hydrobia marginata* occur. These three shells do not occur in the lower terraces, which are respectively about 15 and 8 feet above the alluvium.

**Raised Beaches.**—Elevation of the land is also attested by the raised beaches and sea-margins which occur along many parts of the British coast-line. The beaches consist of sand and gravel irregularly stratified, and often containing drifted shells, such as may be found on modern shores. Deposits of this kind occur at Brighton (see "Physical Geology," p. 55); at Selsea, where a yellow clayey gravel, with large erratic blocks and some few shells of littoral species, overlies an older loamy deposit with many well-preserved shells; at Portland Bill, where

[1] "Geology of Cambridge, Mem. Geol. Survey," p. 82.

the highest part of the deposit is 50 feet above sea-level; and at many places round the coasts of Devon and Cornwall.[1] On the Scottish coasts raised beaches and lines of cliff are found at various successive levels between 25 and 100 feet above high-water mark, four or five sometimes occurring one above another.

**Cave Deposits.**—The origin of caves and the formation of the deposits found in them have been explained elsewhere ("Physical Geology," p. 90). Many such caves have now been explored in England and Wales, and the assemblage of mammalian remains obtained from them is practically the same as that obtained from the river gravels. Many caves have served as dens for hyænas, and the bones of other animals belong to carcases which have been dragged in by these creatures. At other times they have served as shelters for human hunters, whose occupation of them is proved by the frequent occurrence of stone implements—Palæolithic in the lower beds, and Neolithic in the higher. The caves of Creswell Crags in the Magnesian Limestone on the borders of Derby and Notts afford good examples of such deposits. In Robin Hood Cave the beds found were:—

| | Feet. |
|---|---|
| 5. Stalagmite united to the roof | 1 to 2 |
| 4. Breccia with bones and implements | 0 — 3 |
| 3. Cave-earth with bones and implements | 2 — 4 |
| 2. Red clayey sand, with bones | 2 — 4 |
| 1. Light-coloured sand, with blocks of limestone fallen from the roof | 2 |

The lowest sand yielded no organic remains, but the red sand contained bones of many animals, all of them scored with the teeth-marks of the creatures which had dragged them into the cave, and that these were hyænas is proved by the abundance of hyæna bones and teeth belonging to individuals of all ages from cubhood upwards. Flint implements are rare in the sand, but abound in the overlying cave-earth, some consisting of flint and others of quartzite, but all of Palæolithic form; bones of the same

[1] See De la Beche, "Geology of Devon and Cornwall, Mem. Geol. Survey," and W. A. E. Ussher, "Geol. Mag.," 1879, p. 166.

animals occur in this layer. Lastly, in the breccia above, are flint and bone implements of the more highly finished type which is known as Neolithic, and fashioned, according to Professor Dawkins, by a different race of men to the earlier inhabitants.

The Kirkdale Cave in the Carboniferous Limestone of Yorkshire is another well-known example of a hyæna den, and was explored many years ago by Dr. Buckland, who found in it the remains of about 300 hyænas, old and young, together with gnawed bones of many herbivorous animals.

Kent's Cavern, in the Devonian Limestone near Torquay, has been carefully explored by Mr. Pengelly, with assistance from the British Association, and some interesting facts were elicited, the general succession being as follows:—

5. Black mould.
4. Granular stalagmite.
3. Cave-earth, with bones and implements.
2. Crystalline stalagmite.
1. Breccia, with bones of bears and implements.

This cave seems to have been first occupied by bears, and occasionally by men of the Palæolithic race, all the implements found in the breccia being of the more ancient and rude type. In the cave-earth above, hyæna bones are the most abundant, and the implements associated with them are of Neolithic type, some being fashioned of bone.

Some caves overlooking the Vale of Clwyd, in North Wales, have been recently explored by Dr. H. Hicks, who thinks that the oldest deposits in them were introduced in early Pleistocene times before the Glacial submergence, for they occur on the side of a small valley or ravine, which has evidently been filled with boulder-clay and sandy gravel to a level somewhat above that of the highest cave, which is now 62 feet above the stream at the bottom. The bone-beds seem to have been disturbed and mixed with sand and sandy gravel, like that in the valley outside; such a conclusion, if confirmed, would make the immigration of Palæolithic man anterior to the formation of these Glacial deposits, which are of the low-level Lancashire type, and

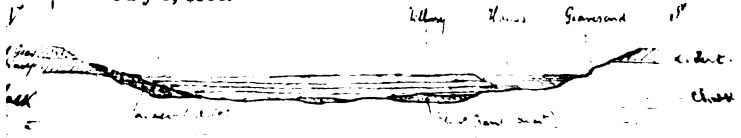
the latest excavations appear to afford the desired confirmation.[1]

**Alluvial Levels.**—Strips of alluvium formed of the deposits left by the flood waters border the channels of all our lowland rivers and widen out in the lower part of the valley, till near the river's mouth they often form wide levels or marshes, which are partly of fluviatile and partly of marine origin. The depth of alluvial matter which occupies the ancient valleys of our rivers near their mouths is sometimes very great; thus at Sheerness, and also at Upchurch, near Sheppey Island, borings have proved 77 feet of such alluvium. In the Essex Marshes there is sometimes 50 feet of alluvial matter. At Yarmouth there is said to be 170 feet, and in the valleys of the Yare and Wensum there appears to be sometimes 60 or 70 feet of alluvium between the present surface and the Chalk which lies at the bottom of the valley.

In the Vale of Pickering, in Yorkshire, a deep deposit of alluvial matter has accumulated behind the bank of boulder-clay which blocks the seaward end of the valley, forming the great "flats" and "ings" near the villages of Wilton, Allerston, Ebberston, and Swainton. The deposits consist of soft clays and sands, which are sometimes 60, 70, and even 100 feet deep, resting usually on a layer of gravel from which a water supply is obtained.

Besides the deposits above mentioned which lie within river-valleys, there are other tracts round our shores which have once been bays and inlets of the sea, and are now filled principally with marine silts and clays, though layers of peat with trunks of trees are frequently intercalated with the silts, and mark pauses in the process of silting up. Many such tracts pass beneath the present beaches, and were evidently once much more extensive than they are now. Such are the marshes near Fleetwood, in Lancashire, the Bridgewater Levels in Somerset, which pass beneath the Bristol Channel, and must formerly have extended far down this estuary, Pevensey Levels in Sussex, and Romney Marshes in Kent, the fens of Cambridge and Lincoln, and the marshes of the East Lincolnshire coast.

[1] See "Quart. Journ. Geol. Soc.," vol. xlii. p. 15, and "Nature," July 8, 1886.



Some of these areas have been previously described ("Physical Geology," p. 191, *et seq.*), and the facts connected with them appear to show that they are all portions of more widely spread plains which may once have extended across to Belgium on the east, to France on the south, and to Ireland on the west. The same phenomena are of frequent occurrence round the shores of Ireland, undisturbed beds of peat being frequently found beneath the sand and mud of the Irish bays and harbours. Professor Jukes remarks that "at numerous points along the south and west coast of Ireland, it is a common practice for the country people to go to the head of the sandy bogs at dead low water of spring-tides and to dig turf from underneath the sand, and it has been equally noted in similar situations along the eastern and northern coasts."[1] The rooted stumps of trees, which are so common in all these submerged peat-beds, prove that the silted-up bays were elevated into dry land, and their present position proves that this land has been subsequently submerged. Bones of elephants, wild oxen, and deer are sometimes found in these beds, associated with stone implements of Neolithic type.

## Physical Geography and Climatal Changes in the British Area.

**Miocene Period.**—From the entire absence of Miocene rocks in Britain we may conclude that the whole of the British area was at this time above the level of the sea, and that it formed part of the great Miocene continent which was mentioned on p. 488. There was, in fact, a continuance of the elevation which was in progress during Oligocene times, and the vertical rise appears to have been greater in the west than in the east, thus imparting an easterly inclination to all the Neozoic rocks, and causing the development of the successive escarpments which they now exhibit; it is indeed possible that this easterly dip was greater in Miocene times than it is at present.

[1] "Manual of Geology," second edition, p. 686.

The physical features of central and southern England appear to date from this period, so far at least as the general contours of the country are concerned. In Oligocene times the courses of the rivers seem to have been very different; the Severn, for instance, may then have been a tributary of the river which had its estuary over the Isle of Wight, and was perhaps deflected to its present course by the rise of the Chalk escarpment in Wilts. The Thames could have had no existence as a separate river until the watershed of the Jurassic escarpment had been formed, and though its valley may possibly have been initiated in Oligocene times, the present system of drainage could only have been developed contemporaneously with the formation of the escarpments; and the same may be said of all the streams which run in the longitudinal valleys parallel to these escarpments.

As regards the general elevation of the country above the sea at this epoch, it is a remarkable fact that our islands are shown by the Admiralty charts to stand upon a submarine plateau, the border of which runs outside the coasts of France, Ireland, and the Hebrides; on this plateau the soundings are everywhere under 100 fathoms (600 feet), but from its surface the sea-bottom slopes steeply down to depths of 1,300 and 1,500 fathoms (9,000 feet), as if its edge had for a long time formed the coast-line of western Europe. This was doubtless the coast-line throughout the whole duration of Eocene, Oligocene, and Miocene times, and during the latter period it is quite likely that Britain stood between 2,000 and 3,000 feet higher out of the sea than it does now; while the mountains of Wales and Scotland may well have been twice as high as they are now, and thus have lifted their crests to 8,000 or 9,000 feet above the sea-level of the period.[1] An elevation of 500 fathoms would almost unite Scotland to Greenland, for there is a ridge connecting these countries where soundings are seldom over that depth and more often between 300 and 400 fathoms. Greenland was doubtless then in connection with America, and no northern currents entered the Atlantic Ocean.

[1] See Boyd Dawkins, "Early Man in Britain," p. 44, and Professor Judd in "Quart. Journ. Geol. Soc.," vol. xxx. p. 259.

The North Sea between Britain and Scandinavia must have formed one of the vast plains of the Miocene continent, and was doubtless watered by the rivers which flowed down from the surrounding highlands, and which united perhaps to form the deep trench-like valley which curves round the coast of Sweden, and the bottom of which lies 200 feet below the average depth of the North Sea. Over the plain now occupied by this sea and across the English Channel some of the Miocene animals must have roamed into England, but the only evidence of their ever having occupied our islands is the occurrence of the bones of certain species in the nodule beds which form the base of our Pliocene deposits. The absence of *Dinotherium* bones among these may possibly be due to the absence of any lakes on the banks of which he could live.

**Pliocene Period.**—At this epoch a movement of subsidence took place by which a part at least of the British area was lowered considerably from the position it occupied in Miocene times. The area of the North Sea was submerged, and the eastern part of England was also depressed beneath its waves. Free communication was thus established between this eastern sea and the Arctic Ocean, enabling northern species of mollusca to spread southward to our eastern coasts. In early Pliocene times there was probably a connection between this sea and the Mediterranean by means of a shallow channel across the south-east of England to Normandy, and thence southward through France, but the limitation of the later Pliocene deposits to the extreme eastern and western parts of England renders it highly probable that at that time the country was once more joined to the continent across the English Channel.

Moreover, it is by no means certain that the north-western portions of the land forming Miocene Britain participated in the subsidence above indicated; this movement may have been like that which has recently taken place in Scandinavia, and the southern districts may have sunk while the northern remained stationary, or were even rising. The recent discovery of the Pliocene beds at St. Erth, while it proves that this area partook of the submergence, affords some evidence in support of the above supposition, for the

remarkable absence of northern species of mollusca in those beds leads Messrs. Kendall and Bell[1] to conclude that this western sea had no communication with the Arctic Ocean, and that land still extended northward from Scotland to Iceland and Greenland, as it did in the preceding period, forming a barrier of separation between the Atlantic and the Arctic Oceans.

Britain therefore in Pliocene times appears to have been so situated that its eastern shores were swept by a cold current from the north, while the temperature of the western coast was kept up by a warm current setting from the south, or by a "gulf stream," as at present; the Atlantic was not, as now, invaded by cold currents from the north, except perhaps towards the close of the period, when by the sinking of the Davis Strait and Baffin's Bay area a cold current from the north-west may have begun to set toward our area; this, however, would hardly cause much refrigeration until a large amount of ice had accumulated in the Arctic regions, as it subsequently did.

The increasing proportion of northern forms in the Crags (see p. 507) may however be taken as an indication that the climate was becoming gradually colder, and that some change either cosmical or geographical was taking place which was increasing the severity of the winters and diminishing the warmth of the summers in our part of the world; and, finally, in the Forest Bed we find a fauna and flora indicative of a climate somewhat colder than that which at present prevails in Norfolk. All this prepares us for the great change which took place immediately after the formation of this bed.

Two important geographical facts are proved by the phenomena of this Norfolk Forest Bed:—(1) the presence of a large river; (2) the silting up of that part of the North Sea in which the Crags had been deposited. There appears to have been a slight elevation of the land at this epoch, bringing the east of England well above the level of the sea, and converting the southern part of the North Sea into a low-lying country covered with forests of spruce and Scotch firs, oaks, beeches, and elms. But, as Mr. C. Reid

[1] "Quart. Journ. Geol. Soc.," vol. xlii. p. 207.

observes,[1] "a most important feature in the physical geography of the period was undoubtedly the large 'Forest-Bed' river," and with the view of determining the direction from which this river flowed, he made a careful examination of the stones composing the gravelly portions of the bed. He found the collection of pebbles to be such that if the river had flowed from the south, west, or north, it must have brought a very different assemblage. "It seems, therefore, that only from the south-east and east could the stones be derived, and that the river must have been very large is shown by the uniformity of the composition of the gravels at considerable distances apart,—if this be the correct reading, the river can be no other than the Rhine, a view held by various writers ever since the Forest Bed was first known." He concludes, therefore, that the estuary of the Rhine at this epoch lay just outside our eastern coasts, and that the Forest Bed was a deposit formed on its banks.

The intercalation of the Forest Bed between two deposits of marine sand proves that the district was but little elevated above the sea, and the *Leda myalis* bed indicates either a submergence or a rapid wasting of the coast under the encroachments of the sea.

**Pleistocene Period.**—The Arctic plants in the thin layer underlying the lowest Boulder-clay of Cromer indicate a great and sudden increase of cold, and the overlying Boulder-clays are the acknowledged product of ice-action, though opinions differ as to whether the principal agent engaged in their formation was marine-ice or land-ice. Before attempting to distinguish between the claims of these two agents let us endeavour to form some idea of the causes which led to this great alteration of climate, and brought Glacial conditions into Britain.

So far as we know there are only two sets of causes which could have wrought such a change; these are (1) cosmical and astronomical causes affecting the whole globe, (2) local and geographical causes involving the connection or disconnection of continents, and the consequent divergence or introduction of marine currents.

[1] "Geology of the Country around Cromer, Mem. Geol. Survey," p. 55.

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(*c*) The great strength of the sun's rays at the beginning of summer would produce an increased amount of evaporation; but the presence of snow-clad mountains would chill the atmosphere and condense the vapour into thick fogs such as envelop the Antarctic regions during summer at the present time. These fogs, by cutting off the sun's rays, prevent the further melting of the snow and ice, and make the summer temperature of these regions actually lower than that of the northern regions, in spite of the summer occurring in perihelion.

(2) Let us next examine the probable geographical conditions of the period. The land connection between Scotland and Greenland has already been mentioned, and there is every reason to suppose that it continued to exist till the beginning of Pleistocene time; all authorities are agreed that the British Islands then stood at a much higher level than they do now, that England was joined to the Continent, and that Ireland was probably united to England, and consequently that all our mountainous regions rose to much greater elevations. It is hardly necessary to point out that a greater extent of land with more lofty mountains are conditions which would favour a greater accumulation of snow.

Assuming, then, the persistence of the barrier between the Arctic and Atlantic Oceans, what changes can be indicated as likely to bring a cold current into the Atlantic from the north-west?—for the existence of such a current seems to be proved by the prevalent direction of ice-marks in England, Scotland, and Ireland, and by the facts connected with the dispersal of erratics. I venture to suggest that the submergence of the Baffin's Bay area may have taken place at this time, and that by this means a cold Arctic current would be introduced into the Atlantic, and would in all probability flow eastward along the western side of that land of which our islands formed a part. Such a current would pick up numerous ice-floes on its way, and would drive them against our shores just as ice is now driven on to the shores of Labrador, and by such an arrangement any warm current such as the modern "gulf

stream" would be cut off from our north-west coasts, and compelled to take a more southerly course.

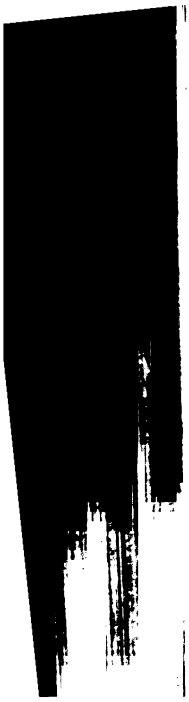
Dr. Croll, however, has adduced very good reasons for supposing that no such powerful current as the Gulf Stream then entered the North Atlantic. He points out that the strength of the trade winds depends on the difference of temperature that may exist between the equatorial and polar regions, the winds being strongest in that hemisphere where the greatest difference exists. When this occurred in the northern hemisphere the influence of the northern trades would extend considerably south of the equator, and this would affect the great ocean currents, tending to impel them southwards. Even as it is, a portion of the Gulf Stream, where it impinges on the eastern coast of South America, is deflected southward along the coast of Brazil, and under the conditions above indicated it is quite possible that the current might be shifted so far southward that the whole of it was similarly deflected into the southern ocean, or that the portion escaping northward was but an insignificant and feeble current. The abstraction of the Gulf Stream from the North Atlantic would have an enormous effect on the climate of Britain, and Dr. Croll calculates that the mean temperature of London would be at once lowered by 40° F.

Such physical and geographical conditions at these, viz., Britain forming a prolongation of Greenland, washed on both sides by cold Arctic currents and deprived of the influence of the Gulf Stream, would be calculated to produce an extreme amount of cold, and if the evidences of a Glacial period were confined to Britain, would be almost sufficient to account for the facts; but since similar phenomena occur over all the northern parts of Europe, Asia, and America, we must admit that the cosmical causes had also much to do with the induction of the Glacial period. An adequate conception of the geographical conditions which probably prevailed at the commencement of the period is essential to the proper comprehension of our Glacial deposits, and the writer thinks that any history of Britain during Pleistocene time should open with such a picture of its geography and hydrographic surroundings as that which has just been sketched.

In the descriptive section it has been mentioned that glaciated surfaces are common throughout the northern parts of Britain, and that similar markings occur beneath the Boulder-clays which cover the lowlands; much of this glaciation was doubtless effected by land-ice at the commencement of the period, when the land stood at a high level. The country seems then to have been covered by a vast system of glaciers, which may have been confluent on the lower ground, and have formed an ice-sheet like that which envelops Greenland at the present day. The Highlands of Scotland evidently formed the largest centre of dispersal, but independent snowfields existed over the southern uplands, the English Lake District, Wales, and Northern Ireland. The principal result of these slowly-moving ice-caps may be described as a general scraping and scouring out of the land beneath them; all its rocky prominences were smoothed and rounded off, the pre-glacial soils and river gravels, and the outer weathered portions of all rock-surfaces, were ground up and pushed along down the valleys and out on to the plains below.

The hard Till or Lower Boulder-clay is believed to have been formed under this ice-sheet, and some authorities consider it to have been accumulated as a "moraine profonde" beneath the ice which rested on the land; but others question the possibility of such an universal layer of detritus existing beneath an ice-sheet, and suggest that this Boulder-clay was laid down below the level of the sea, where the ice displaced the sea-water, but began to rise or lift itself from the ground over which it passed.

With regard to the later Boulder-clays, and those which spread over so large a part of England, there can be little doubt that sea-ice was chiefly concerned in their formation; all admit that after the ice had reached its maximum thickness and extension, a general movement of submergence set in, which brought the sea-ice farther and farther over the land. During this phase of the period the outer parts of the ice-sheet would be broken up by the sea-waves, the huge icebergs thus formed being mingled with the floes brought from more northern regions by the two Arctic currents, and both yielding their burdens of mud and stones to swell the deposits of Boulder-clay that were



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that stones and boulders derived from sites at comparatively low levels were carried up to the positions where they are now found. It was also by the occasional grounding of large floes and bergs that portions of the sea-bottom, outside the influence of coast-ice, were torn up and carried forward, to be incorporated with the Boulder-clays of Aberdeen and Yorkshire.

Lastly, the so-called interglacial deposits, *i.e.*, beds of clay and peat with remains of terrestrial plants and animals, are what we might expect to find under such conditions, for as successive portions of the land were brought beneath the sea, many such lacustrine beds situate in protected spots might escape destruction, and while still covered with frozen water might be buried under the ever-advancing deposit of Boulder-clay.

Mr. Mackintosh thinks that the water-worn character of the pebbles in the high-level stratified Drift of Wales, as contrasted with the angular character of the blocks at lower levels, indicates a decrease in the rate of submergence, and says, "at this period the district was probably in the condition of a littoral zone, which may have lasted for a time sufficient to enable the waves to round the stones, and to allow the Mollusca to multiply in the littoral and sub-littoral zones."[1] The occurrence of such shelly gravels at about the same level in Ireland, Wales, and at Macclesfield Forest confirms this idea of Britain having remained stationary for some time when the sea was at this level. It must be remembered, too, that the submergence of the land would partially ameliorate the severity of the climate and enable some Mollusca of less Arctic habit to live in the sea which then covered our islands.

From the icy sea by which it was submerged Britain gradually rose again, and as the mountains rose higher and higher above the water they were again covered by ice and snow, but these did not accumulate to anything like their previous thickness, because the conditions which had caused the Glacial episode in the northern hemisphere were now passing away. Snowfields, however, formed on the hills of Scotland, Ireland, Cumberland, and Wales, generating

[1] "Quart. Journ. Geol. Soc.," vol. xxxvii. p. 362.

local glaciers, which have left small moraines to mark the limits of their descent. The lower ground, when it rose above the sea, appears to have been quite free from permanent snow, and was tenanted by the numerous animals which have left their bones in the caves and the river-gravels.

The rainfall, however, was probably greater than it is now, and the country being covered with an almost universal mantle of Boulder-clay, no large tracts of pervious rock were then exposed, such as now absorb a portion of the rainfall; consequently, nearly all the rain was shed off the land in the shape of running water, all the streams and rivers were larger and swifter than they are at present, and the process of valley erosion was thus carried on at a rapid rate.

Since the Glacial deposits to a great extent draped the pre-glacial surface of the country without completely filling up the pre-existent valleys, the streams were naturally directed into the same depressions; but the channel which each began to carve out of the Glacial Beds did not everywhere coincide with that of the river which occupied the valley in pre-glacial times, so that in many cases we have a post-glacial valley system superimposed upon an antecedent one, as in the case of the Mersey and of many rivers in Scotland ("Physical Geology," p. 61). Cases also occur where the older valleys have been so blocked up by Glacial deposits at certain points that the post-glacial streams were ponded back, and have made new channels for themselves through the country between the older valleys; interesting instances of this occur in Lincolnshire.[1]

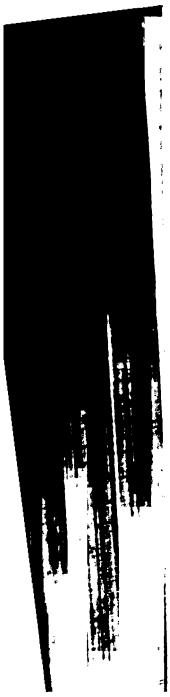
It was, therefore, during the gradual elevation of the country from the great submergence that our river-valleys acquired their present features, their excavation by the rivers which now occupy them being attested by the several terraces or banks of river-gravel which were formed during the process. The upheaval appears to have been an interrupted movement with frequent pauses, allowing the sea to form lines of cliff and beach at successive intervals, and this upheaval appears to have been continued till the

[1] See "Quart. Journ. Geol. Soc.," vol. xl. p. 160.

whole of England[1] stood considerably higher out of the sea than it does now—certainly 150 feet, and perhaps 250 feet higher—this greater elevation enabling the rivers to cut their valleys everywhere down to a much lower base-line than they possibly could do under existing circumstances. The British rivers must all have had much longer courses; the English Channel, where soundings seldom exceed 35 fathoms (210 feet), was doubtless a wide valley through which the united waters of the Seine and Somme, with many tributaries from our southern coast, ran westward to the Atlantic; the Bristol Channel was a similar valley, watered by the continuation of the river Severn; the Thames was a tributary of the Rhine as in Pliocene times, the latter probably flowing nearly due north through the plain of the German Ocean and receiving not only the Thames, but all the other rivers which flow through our eastern counties.

Across the valley of the English Channel the large continental mammalia once more migrated into Britain, and in their train came the earliest human inhabitants of our country. It was probably at this time that most of the caves were occupied by hyænas, for many caverns occur in situations to which there could only have been access at a time when the land was higher, and before the valleys had been cut to their present depth. Thus Professor Boyd Dawkins, alluding to a cave on Caldy Island off the coast of South Wales, remarks: "The discovery of mammoth, rhinoceros, horse, Irish elk, bison, wolf, lion, and bear on so small an island as Caldy, indicates that a considerable change has taken place in the relation of the land to the sea since those animals were alive. It would have been impossible for so many and so large animals to have obtained food on so small an island. It may, therefore, be reasonably concluded that when they perished in the fissures Caldy was not an island, but a precipitous hill overlooking the broad valley now occupied by the Bristol Channel, but then affording abundant pasture. We must,

[1] It is not certain whether Scotland participated in these later movements to the same extent as England. Mr. Hugh Miller tells me there is no proof anywhere north of Durham that the valleys were cut to a much lower base-line than they could be at present.



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any violent cataclysm, or by any event which caused a sudden destruction of the Pleistocene world, and prepared a new surface for the occupation of Mankind, for, as we have seen, Man was contemporaneous with the extinct Pleistocene animals, and their extermination was probably in great part due to his agency. The present time is to all intents and purposes a part of Pleistocene time, and it is as illogical to separate them in a geological treatise as it is to separate the Pleistocene from the Pliocene under such names as Post-Tertiary or Quaternary.

# APPENDICES.

## A. *Devonian Rocks of South Devon.*

An excellent *résumé* of the South Devon succession, so far as it is known, is given by Mr. Ussher in the "Proceedings of the Geologists' Association," vol. viii., with the following comparison of the series found near Plymouth with that established by Mr. Champernowne near Torquay:—

| Plymouth Type. | Torquay Type. |
|---|---|
| A. Picklecombe and Staddon grits, which are faulted against B., so that some beds are probably missing here. | 7. Cockington Beds—purple and grey grits and slates. |
| | 6. Berry Park Beds—bluish and dark olive slaty shales. |
| | 5. Ramsleigh limestone. |
| B. Green slates of Raine Head. | [1] Dartmouth slates—greenish. |
| C. Lilac and grey slates, with local ash-beds. | 4. Ashprington series—diabasic tuffs and lavas interstratified with slates. |
| D. Plymouth limestone, passing westward into calcareous shales. | 3. Stringocephalus limestone of Torquay, Ogwell, and Chudleigh. |
| E. Red and greenish slates. | 2. Purple and greenish slates. |
| F. Looe grits and schists. | 1a. Red grits of Lincombe and Warberry Hills. |
| | 1. Meadfoot Beds—grey grits and schists. |

The correlation of these groups with those of North Devon is very difficult, because they are less fossiliferous, and their lithological characters are less sharply contrasted

[1] The position of these slates is doubtful.

than those of the North Devon groups; but the following correlation is suggested:—

| | |
|---|---|
| No. 7 = Pickwell Down grits, | Upper Devonian. |
| No. 6 = ? | |
| No. 5 is a local limestone, | |
| Dartmouth slates = Morte slates, | Middle Devonian. |
| No. 4, No. 3, No. 2 } Ilfracombe series, | |
| No. 1a = Hangman grits, | Lower Devonian. |
| No. 1 = Lynton Beds, | |

### B. *Pliocene Beds in Kent.*

The age of the beds referred to at the top of p. 496 was for a long time uncertain. They consist of sand with thin layers of ferruginous sandstone containing casts of shells, and they lie in patches along the North Downs of Kent and Surrey, at elevations of over 600 feet. They were first described by Professor Prestwich in 1857, who referred them to the Pliocene period, though few of the fossils then found could be identified with any certainty. Quite recently[1] they have been examined by Mr. C. Reid of the Geological Survey, who has been able to identify a larger number of fossils, and finds that out of 24 species two or three are Miocene forms, and the rest are Pliocene forms, the whole fauna having a southern aspect, like that of the Coralline Crag. He considers the beds to be of older Pliocene age; among the fossils are *Terebratula grandis*, *Astarte Basteroti*, *Cardita senilis*, *Pectunculus glycimeris*, *Turritella incrassata*, and *Pyrula reticulata*.

[1] See "Nature" for August, 1866, p. 341.

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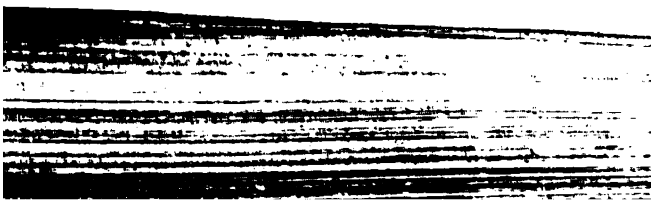

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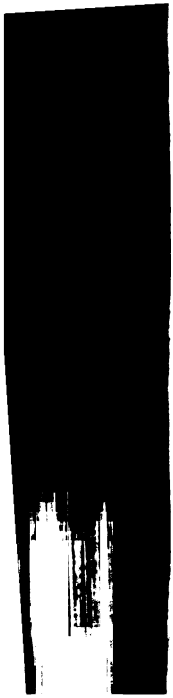

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